Confirmation Review Criteria

1. Do the Mission Design, Spacecraft and Instrument Design, as presented at PDR reflect a PDR level design that meets science requirements?

a. Have all requirements been allocated in the design presented at PDR?
b. Are all system and subsystem requirements documented?
c. Are all system level trades studies complete?
d. Has the system architecture been established and all external interfaces identified?
e. Are the interface definitions at the PDR level?
f. What is the design heritage of the spacecraft systems and instruments?
g. Are the launch vehicle interfaces defined?
h. Are the maneuver and ephemeris data at PDR level?
i. Is the mission design team in place?
j. Is there a baseline trajectory defined?
k. Does the mission design support the science goals?
l. Does the design of the scientific instruments provide data to meet the scientific goals?
m. Are the interfaces to the instruments well designed?
n. Is there a Mission Operations Plan documented?
o. Is the mission operations concept supported be design choices?
p. Does the mission concept permit a smooth transition from initial operations and on-orbit checkout to subsequent mature operations?

2. Are the Management Processes used sufficient to develop and operate the Mission?

a. What is the systems engineering and management approach?
b. Does the project have a complete WBS?
c. Are the tasks for each WBS defined at a PDR level?
d. Are the receivable/deliverables defined for each task at a PDR level?
e. Is there a project management system in place or planned that tracks the status of each task and deliverables?
f. Are the organizations involved using a common project management system?
g. Are the descope plans unchanged from the Step 2 proposals?
h. Has the project quantified the potential cost, mass and schedule impacts/ improvements for each descope option?
i. Have decision points for descope options been identified or defined?
j. Are the risks defined at the mission level?
k. Is there a process defined to gather and assess risks?

l. Are the impacts in terms of schedule, mass, and cost identified for each risk item?
m. Are backup or mitigation plans identified for each risk?
    a. n Are decision points identified for risk items?
n. Are the mitigation plans realistic and do they result in a viable descoped mission?
o. Are agreements in place for use of facilities for testing? Do the schedule windows permit flexibility?
p. What is the experience in the last 10 years of key project personnel?
q. Are the roles and responsibilities of each organization clearly define?
r. What oversight/ insight is being used by GSFC in their areas of responsibility?
s. How have changes from the step 2 proposal been recognized in management, technical, cost and schedule impact/ How have they been resolved?
t. What changes to standard processes are being made to accomplish a "smaller, faster, cheaper mission"
u. How are the large number of participants/ instruments being accommodated/ managed?
v. Is there a intersite delivery plan or matrix?

3. Do cost estimates, control processes, and schedule indicate the mission will be ready to launch on time and within budget?

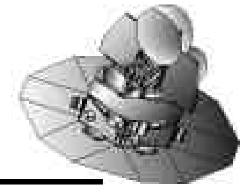
a. What is included in the project budget and what is covered elsewhere?
b. For items covered outside the project budget, is there sufficient budget planned? Could the project cover shortfalls for these items with the project budget?
c. Does the cost analysis indicate the mission will stay within the project budge?
d. How does the current cost estimate and burn rate compare to the baseline?
e. Are the cost reserves sufficient to deal with potential risks?
f. What cost and schedule monitoring and control processes are in place?
g. Is earned value being used? Across the project or within some organizations?
h. How are the program cost caps reflected in contracts and allocated?

SCIENCE OVERVIEW

Chuck Bennett

P. I.

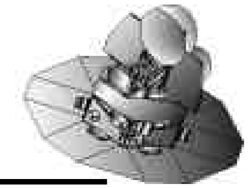
SCIENCE TEAM MEMBERS



- Goddard
  - ***C. Bennett, P.I.***
  - ***G. Hinshaw***
  - ***J. Mather***
- Princeton University
  - ***N. Jarosik***
  - M. Limon
  - ***L. Page***
  - ***D. Spergel***
  - ***D. Wilkinson***
- NRAO
  - E. Wollack
- U. Chicago
  - ***S. Meyer***
- U. British Columbia
  - M. Halpern
- SAO
  - G. Tucker
- UCLA
  - ***E. L. Wright***

Co-I

SCIENCE QUESTIONS

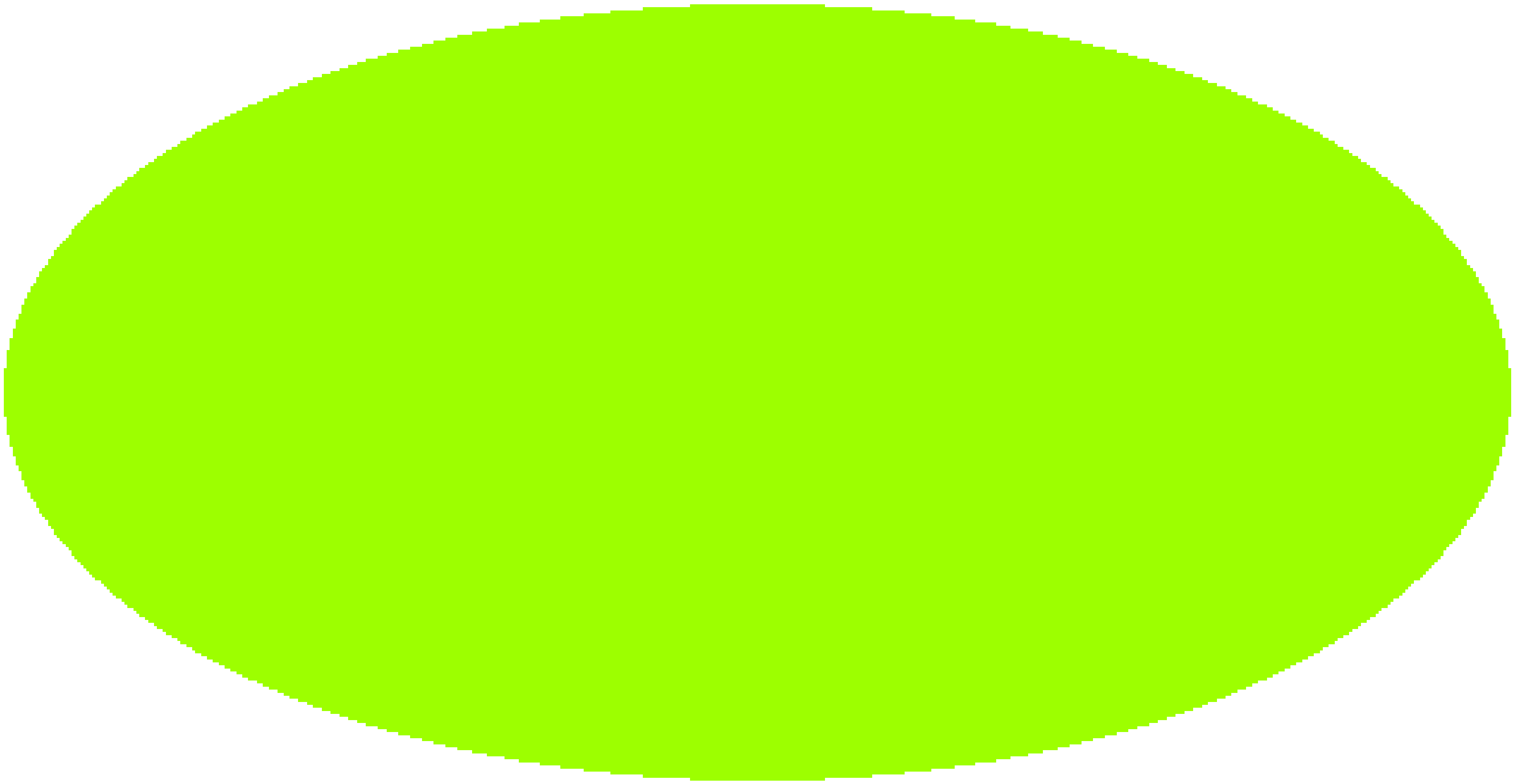


- How did structures of galaxies form in the universe?

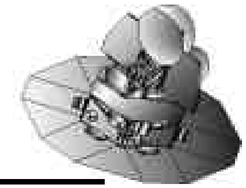
- What are the values of the key parameters of the universe?

- When did the first galaxies form?

ISOTROPY OF THE COSMIC MICROWAVE BACKGROUND

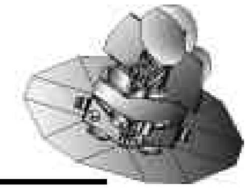


WHAT THE BIG BANG THEORY DOES ***NOT*** EXPLAIN!

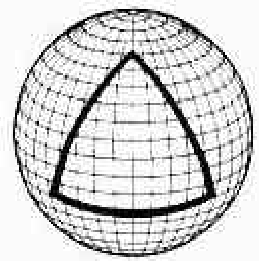


- THE FLATNESS PROBLEM
- THE HORIZON PROBLEM
- THE STRUCTURE PROBLEM

MASS DENSITY / GEOMETRY OF THE UNIVERSE

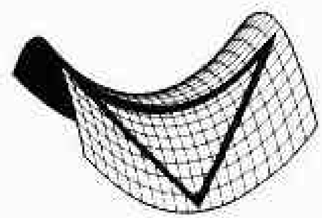


$\Omega_0 > 1$



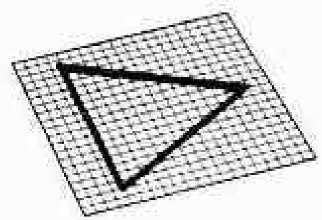
Closed Geometry

$\Omega_0 < 1$



Open Geometry

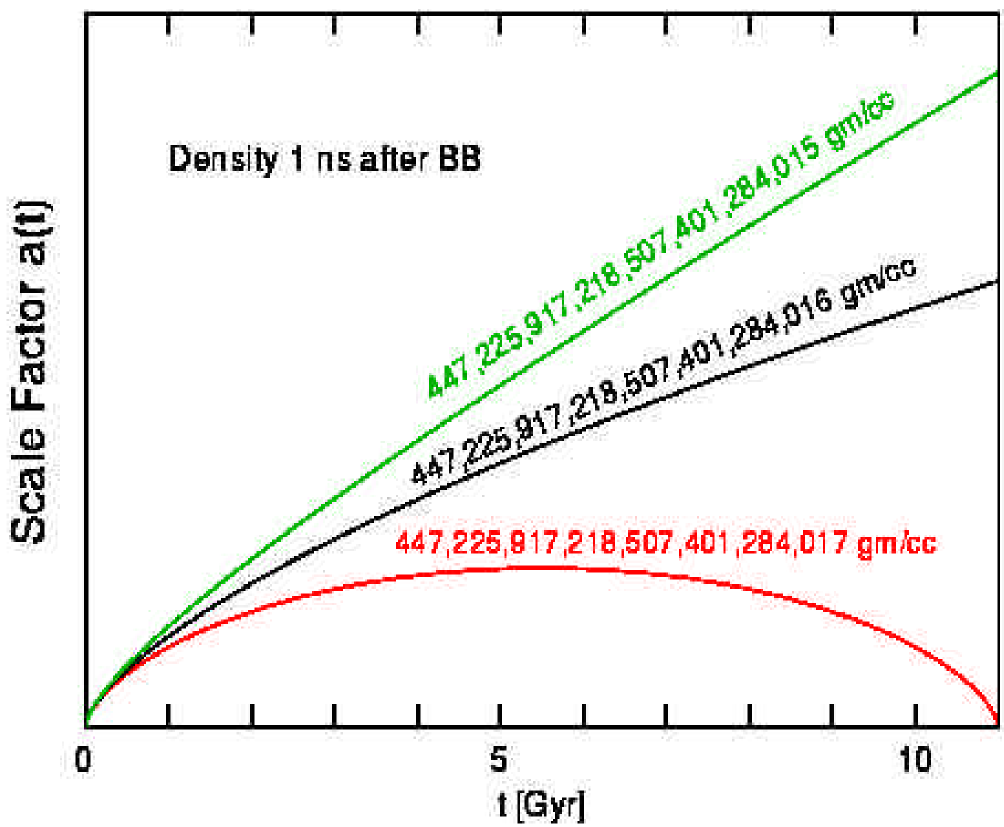
$\Omega_0 = 1$



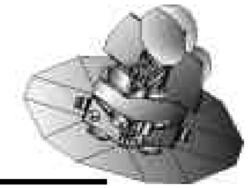
Flat Geometry

THE FLATNESS PROBLEM

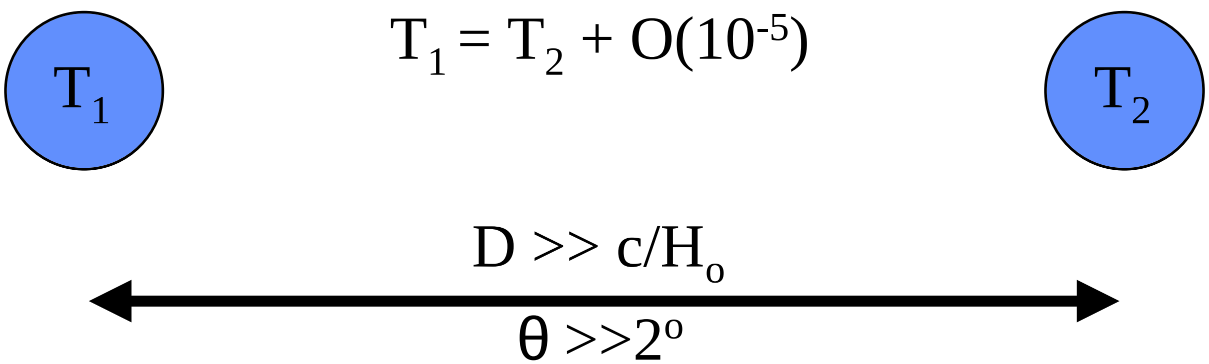
Why is the universe anywhere close to $\Omega_0 = 1$ now?
$\Omega_0 = 1$ is an unstable stationary point.



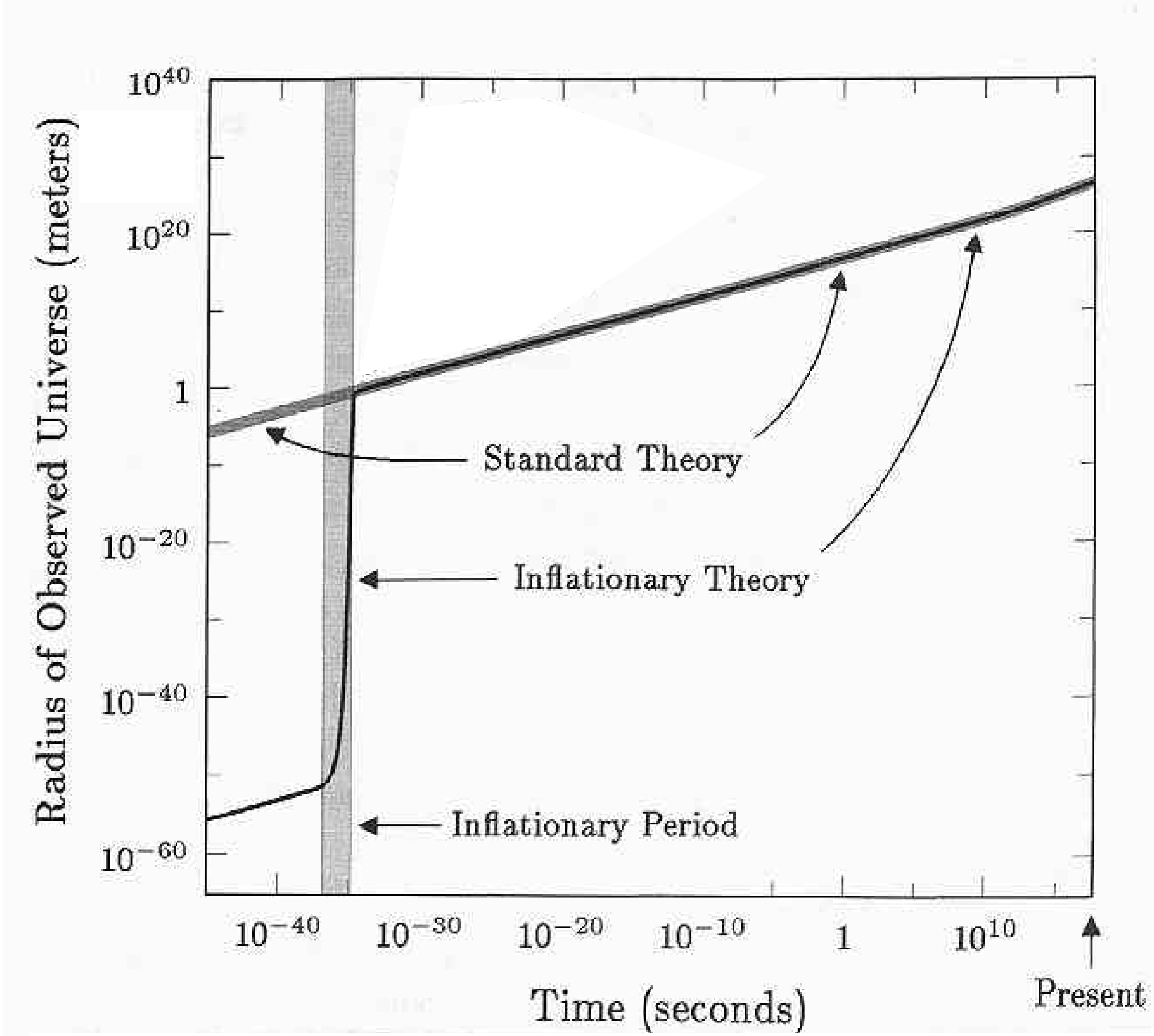
THE HORIZON PROBLEM



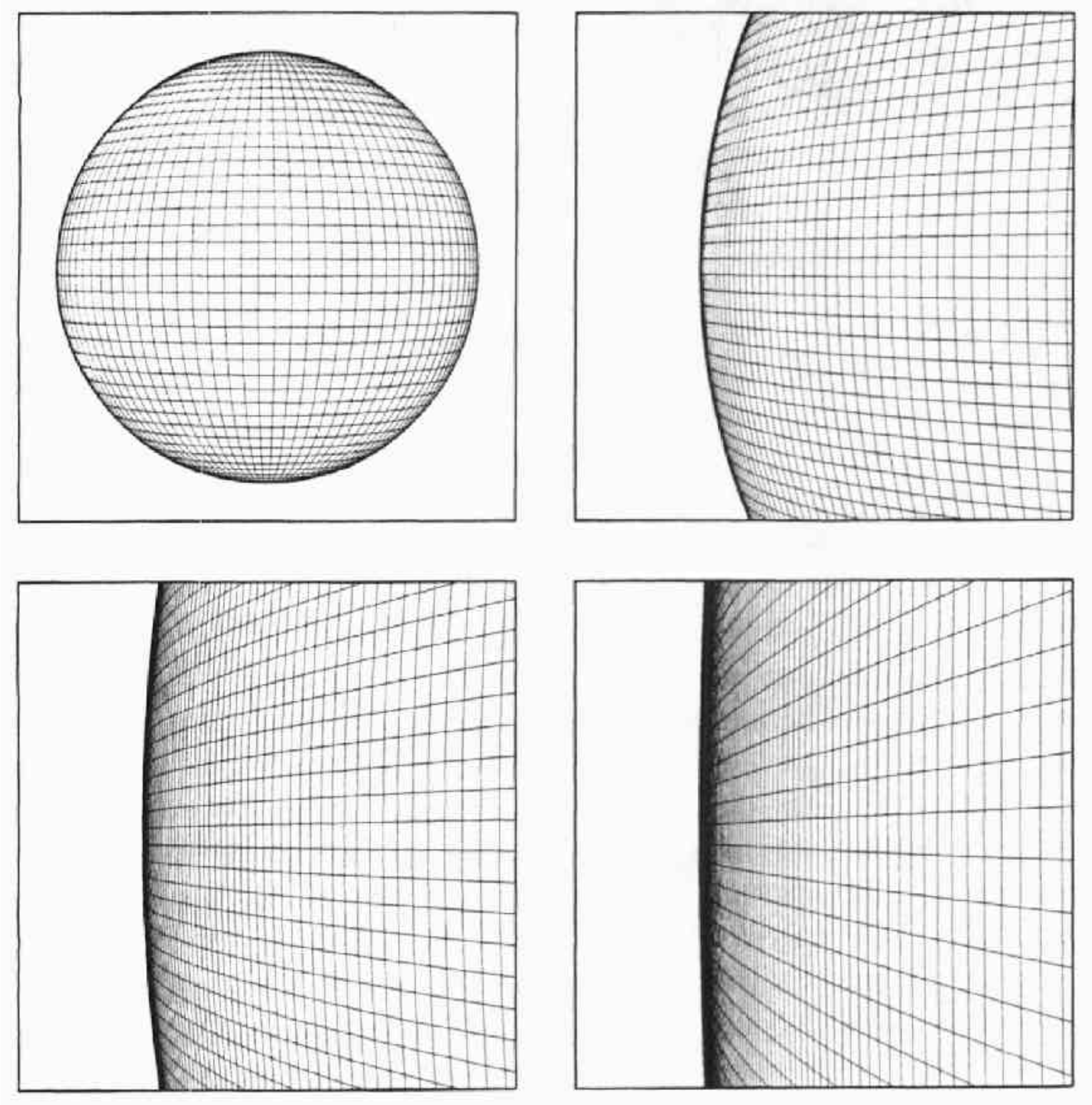
Why is the cosmic microwave background temperature so uniform on scales $>2^o$?



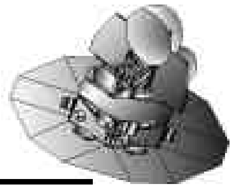
INFLATIONARY BIG BANG VS. STANDARD BIG BANG

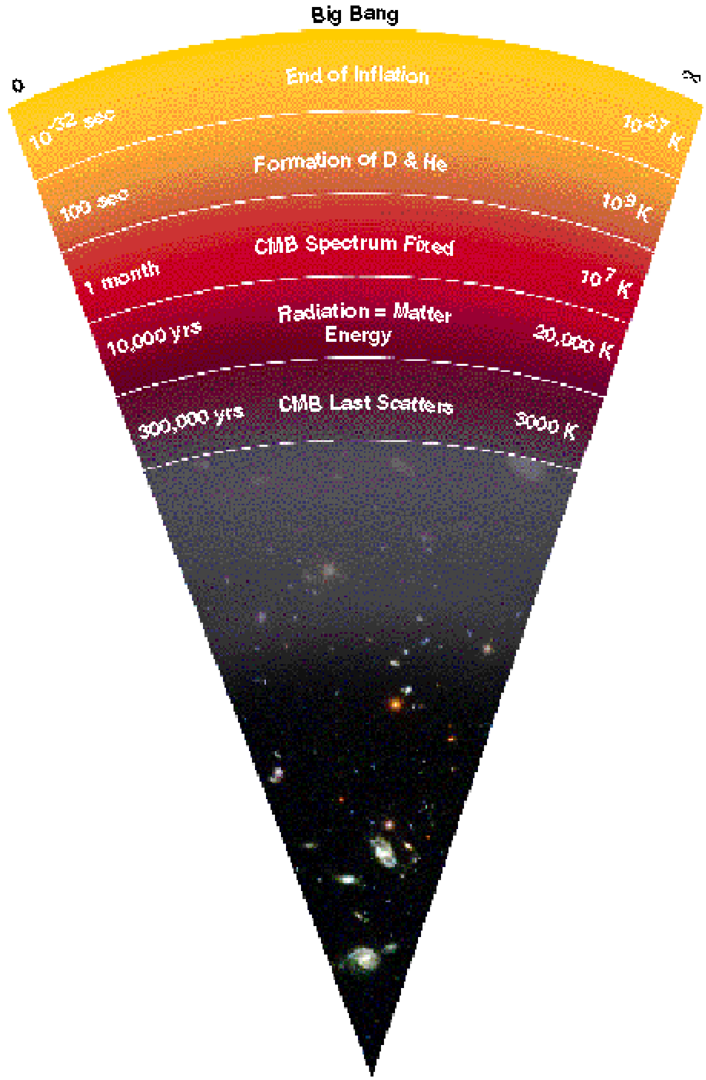


INFLATE TO LOCALLY FLAT SPACE



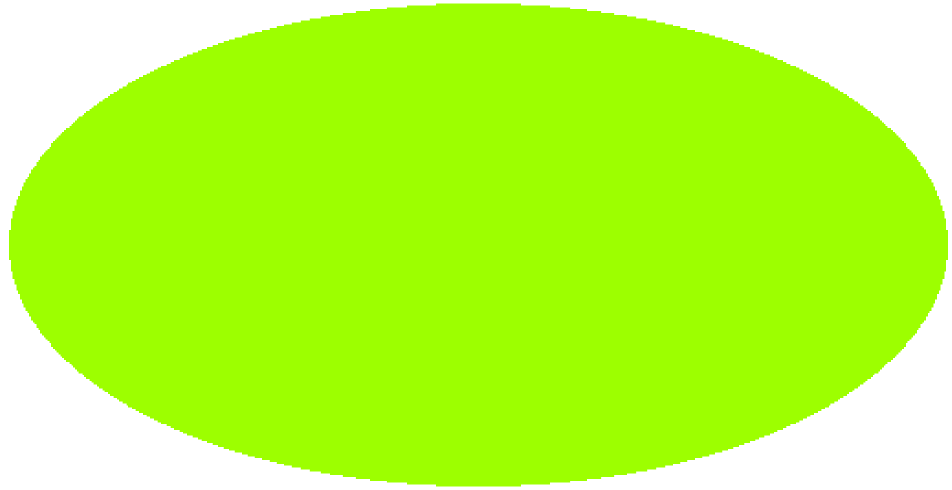
COSMIC HISTORY





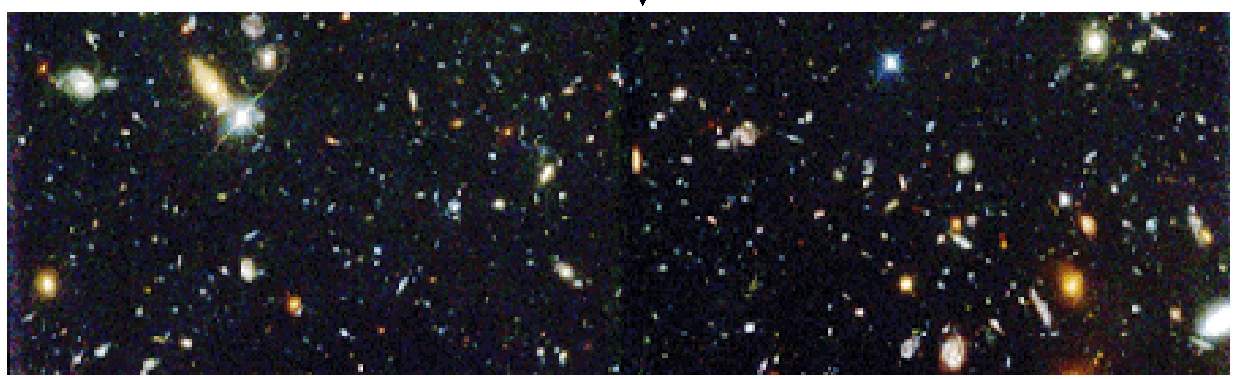
THE STRUCTURE PROBLEM

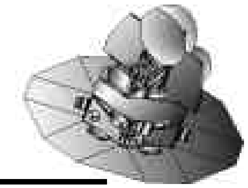
Smooth 3 K
cosmic microwave
background radiation



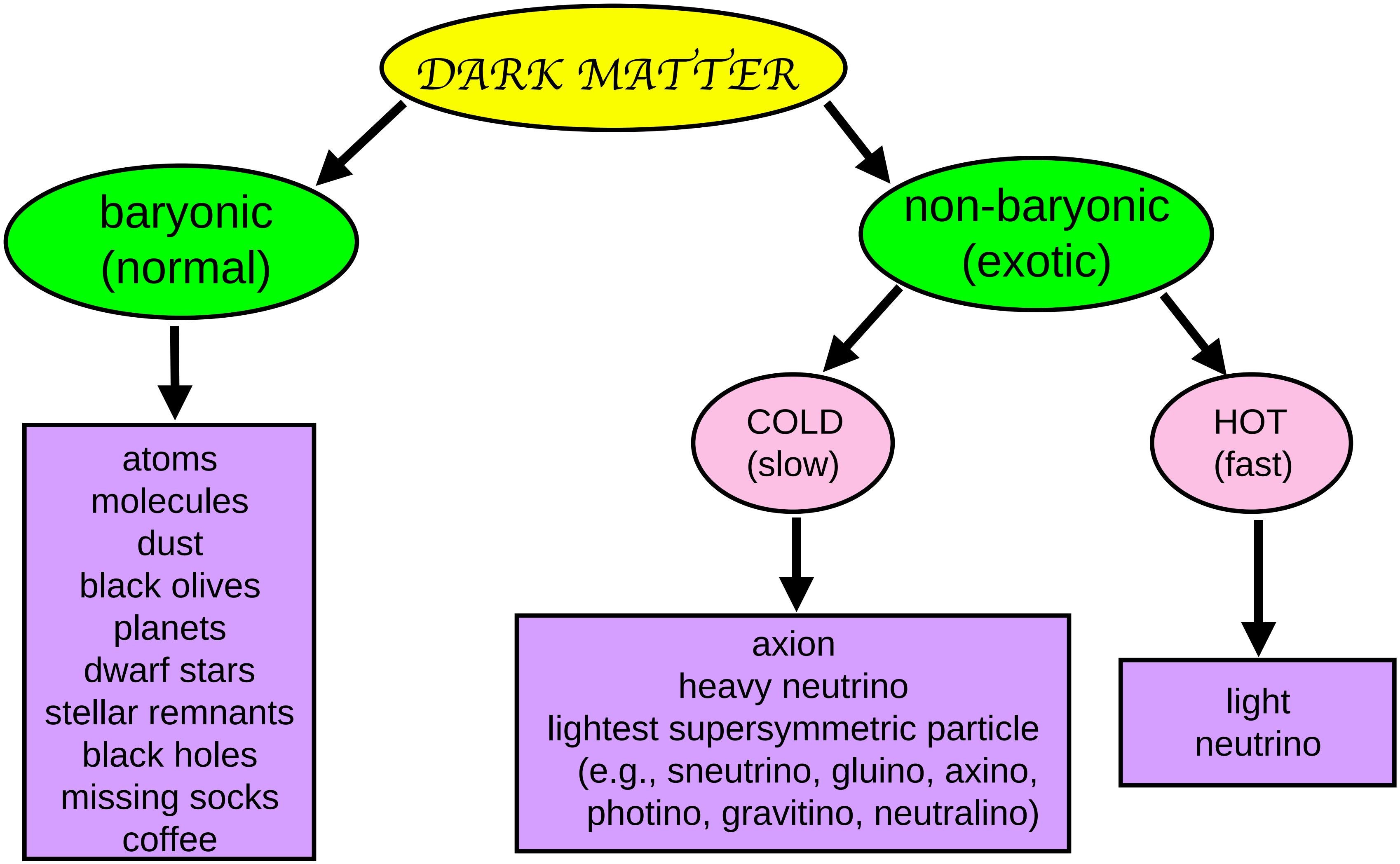
?

Clumpy distribution
of galaxies





DARK MATTER TAXONOMY



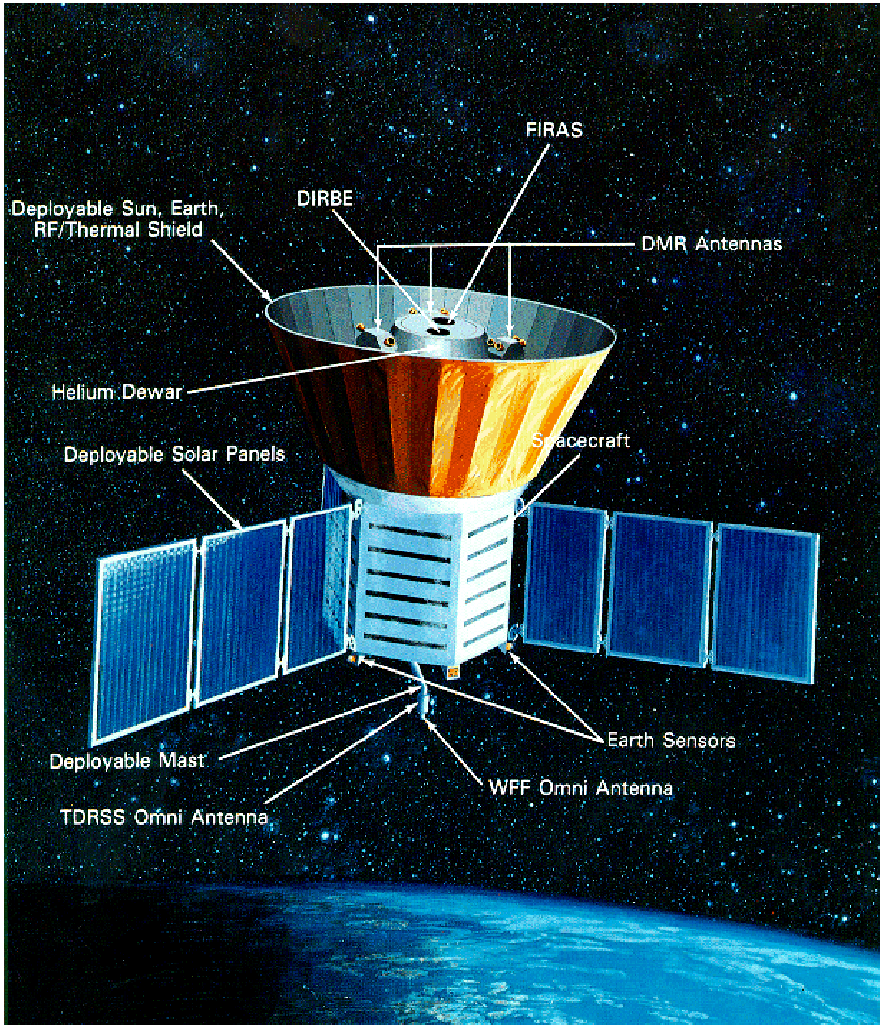
COBE RESULTS

WHAT

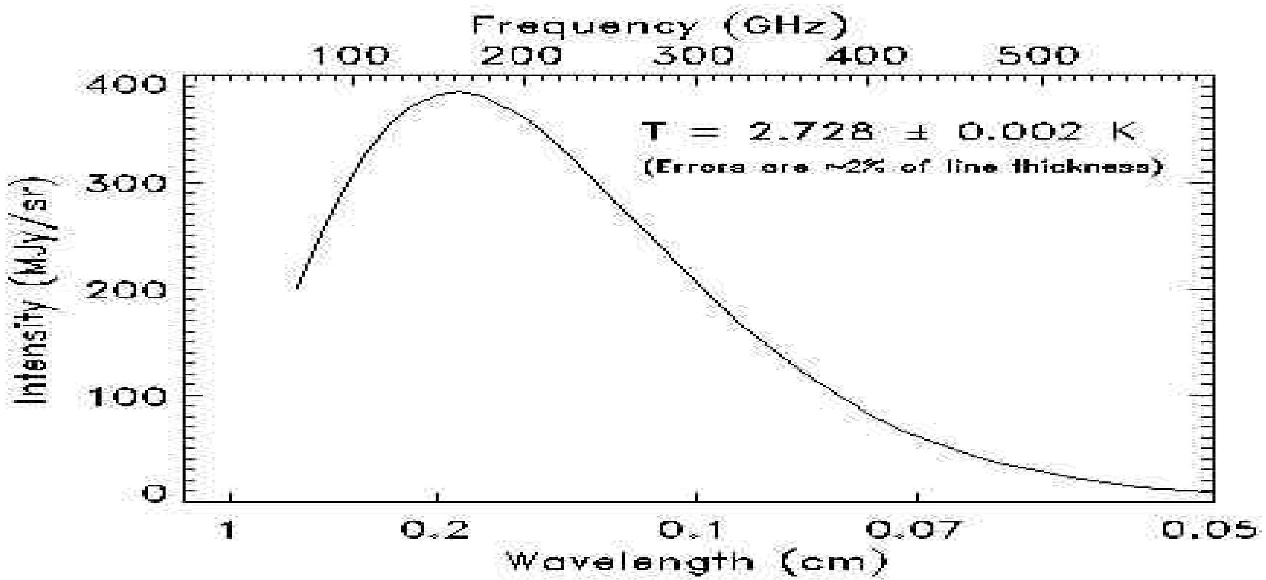
DID WE

LEARN FROM

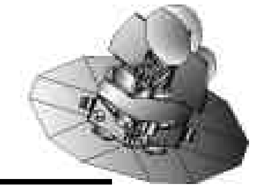
COBE???



SPECTRUM OF THE COSMIC MICROWAVE BACKGROUND



WHAT DID/DIDN'T WE LEARN FROM COBE



- ***DID*** LEARN FROM COBE (7° resolution map)
  - blackbody spectrum: further strong support for Big Bang Theory
  - 1st detection of anisotropy supports gravity as prime force, assuming most matter in the universe is nonbaryonic dark matter
  - matter clustering pattern on large scales (consistent with inflation prediction)

$> 2^\circ$

$< 2^\circ$

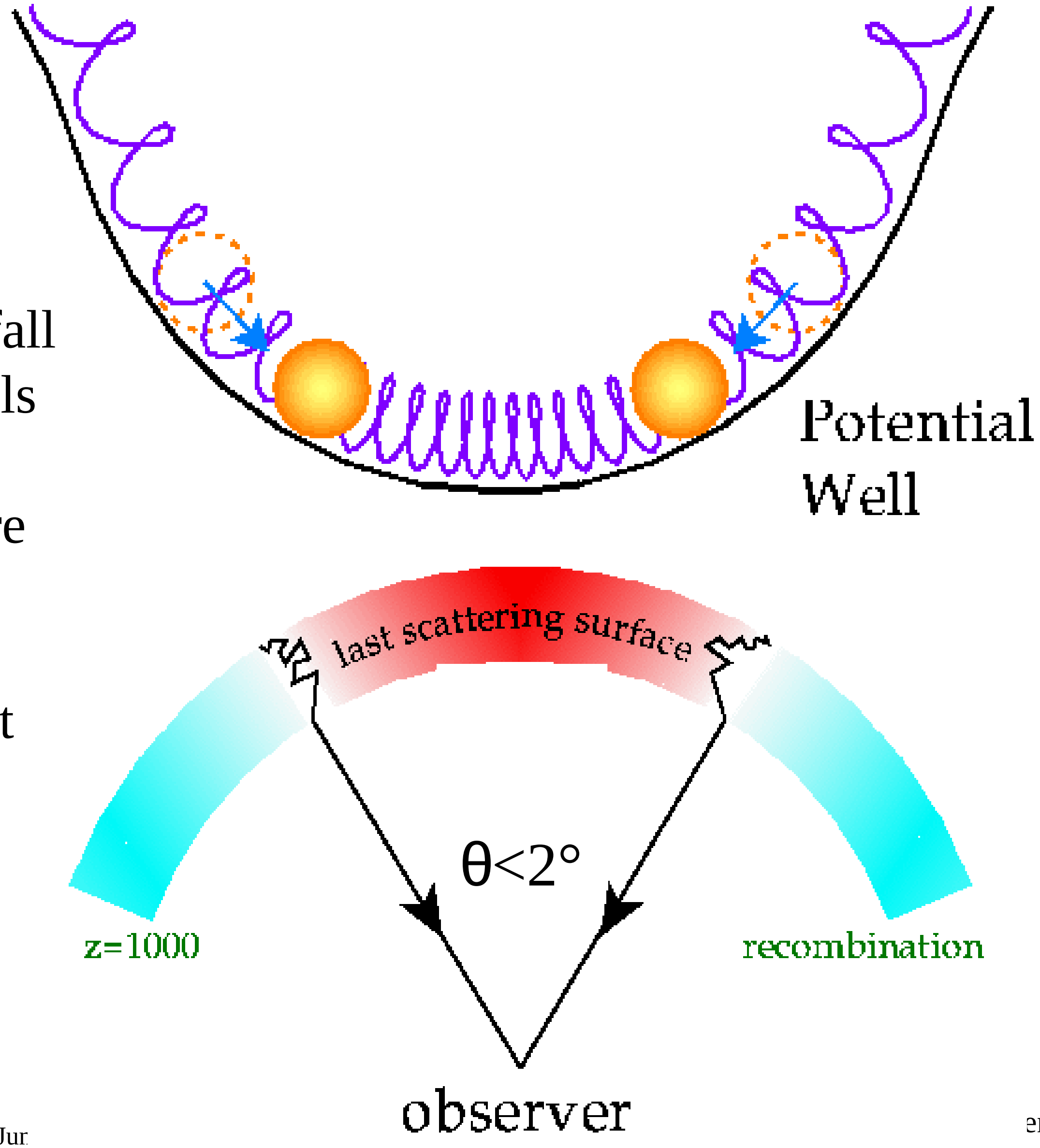
- ***DIDN'T*** LEARN FROM COBE (<0.3° resolution map)
  - What is the mechanism of stucture formation?
    - space-time defects? explosions? non-gravitational effects? other exotica?
    - detailed tests of inflation
  - What are the key parameters of cosmology?
    - open or closed universe?; zero cosmological constant?; Hubble constant?
    - how much baryonic & nonbaryonic dark matter?; "hot" or "cold" dark matter?
  - When did the first stars and galaxies form?

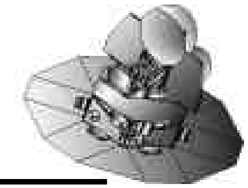
PHOTON-BARYON FLUID ACOUSTIC OSCILLATIONS

Gravity tries to make the matter fall into potential wells

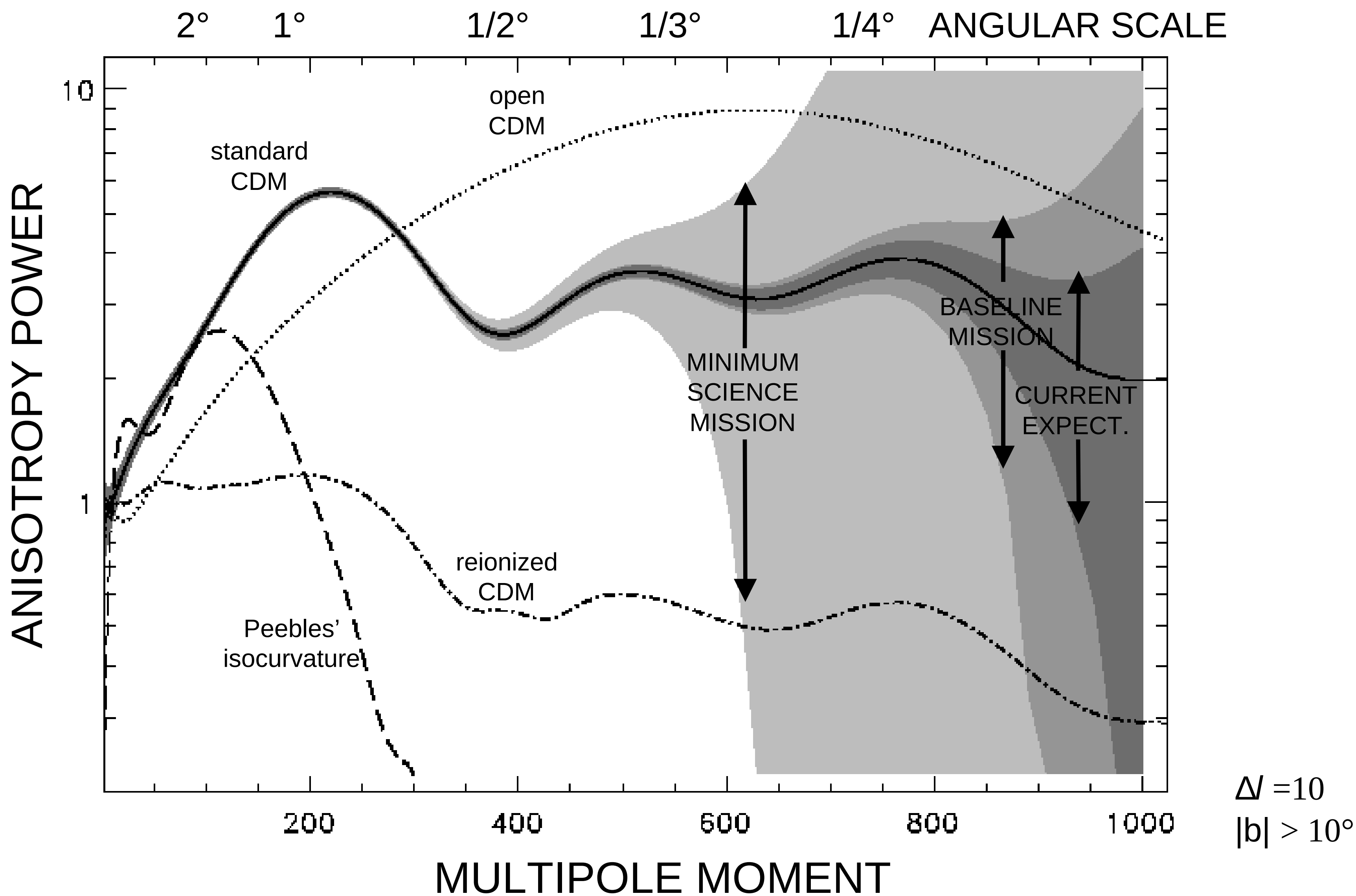
Radiation pressure pushes back

Oscillations result

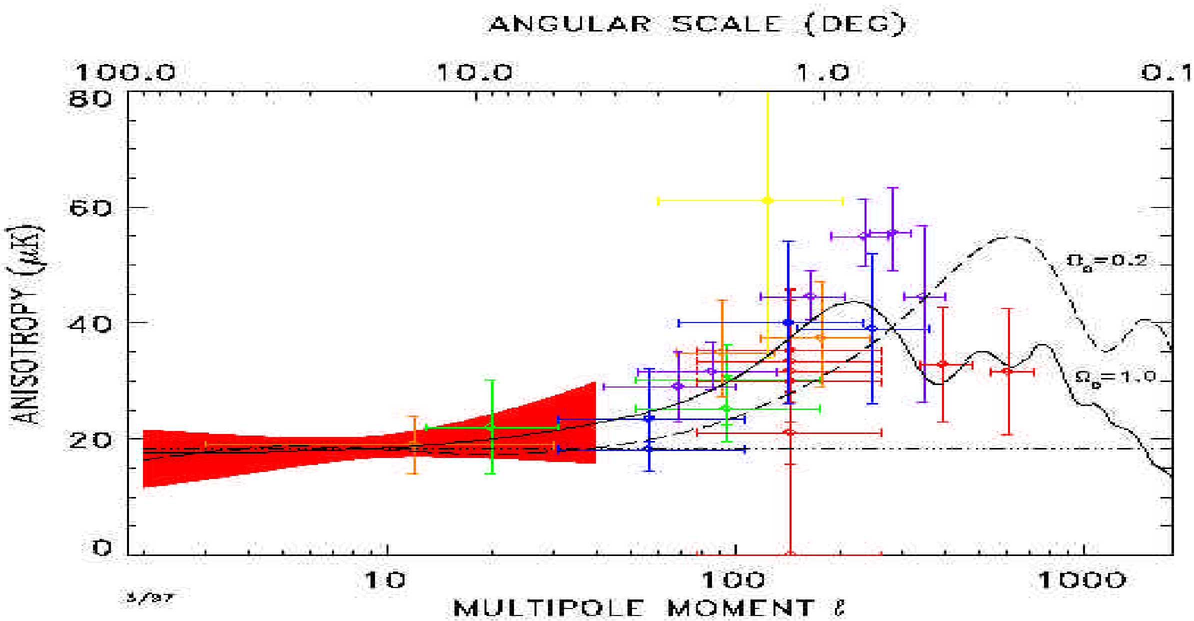




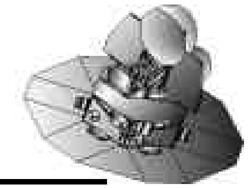
MODEL POWER SPECTRA VS. REQUIREMENTS



CURRENT CMB POWER SPECTRUM MEASUREMENTS



PHOTON-BARYON OSCILLATOR



- restoring force: radiation pressure (ρ_γ)
- mass: baryon density (ρ_b)

$\}$ oscillator "k/m"

(ρ_b / ρ_γ) $\Omega_b h^2$

- driving force:

  primordial gravity fluctuations (inflationary parameters)

  amplified by the nonbaryonic & baryonic dark matter

  inflation: baryons amplify odd peaks, suppress even peaks

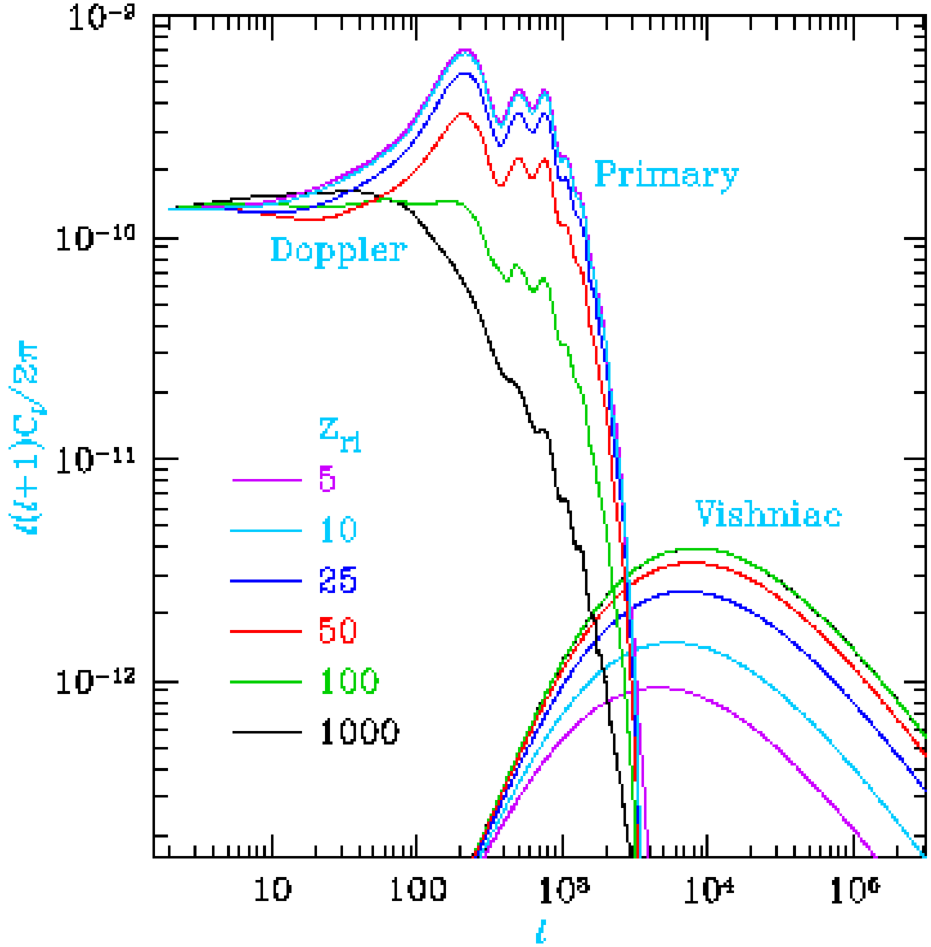
  isocurvature: baryons amplify even peaks, suppress odd peaks

  MDM supresses heights of 2nd, 3rd, etc. peaks

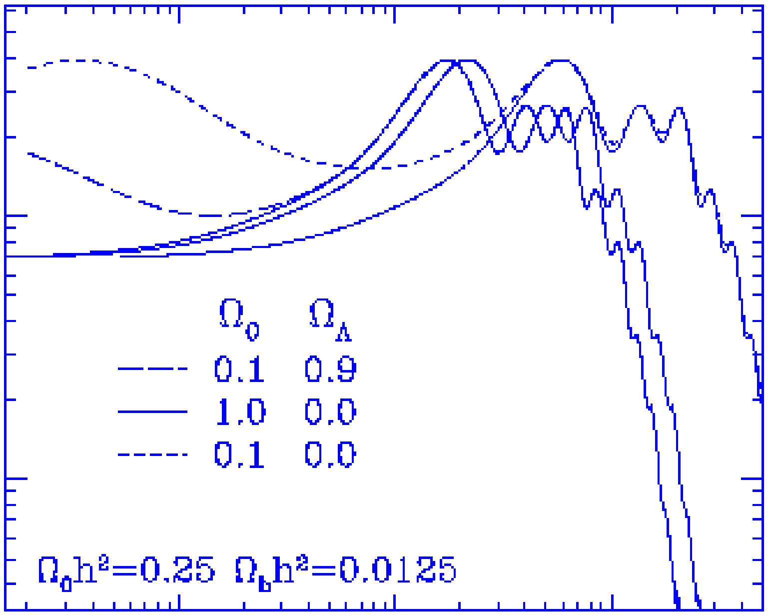
  self-gravity of the fluid $\Omega_b h^2$

- damping force: baryon drag (ρ_b)
- projection effects: Ω_0, Λ_0
- evolution of the grav potential ($\Omega_0 h^2$) H_0

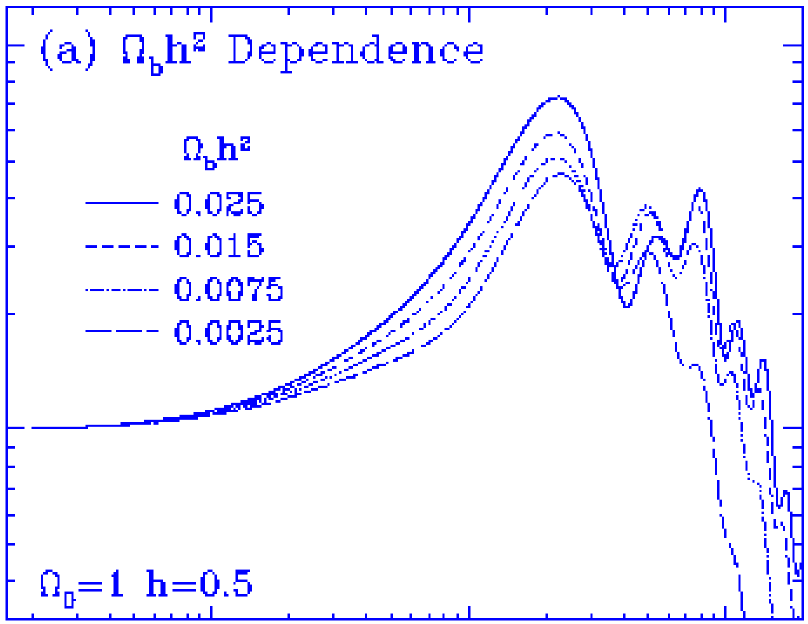
REIONIZATION



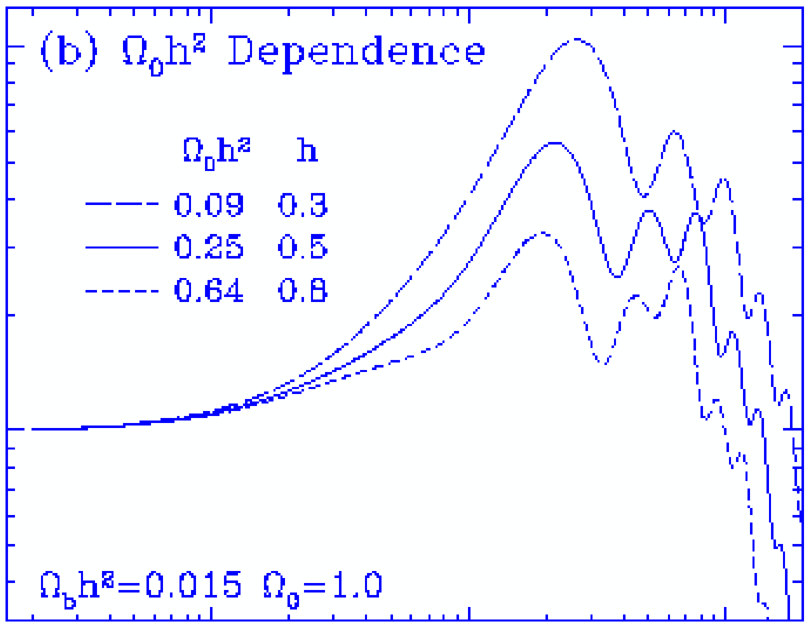
GEOMETRY OF THE UNIVERSE



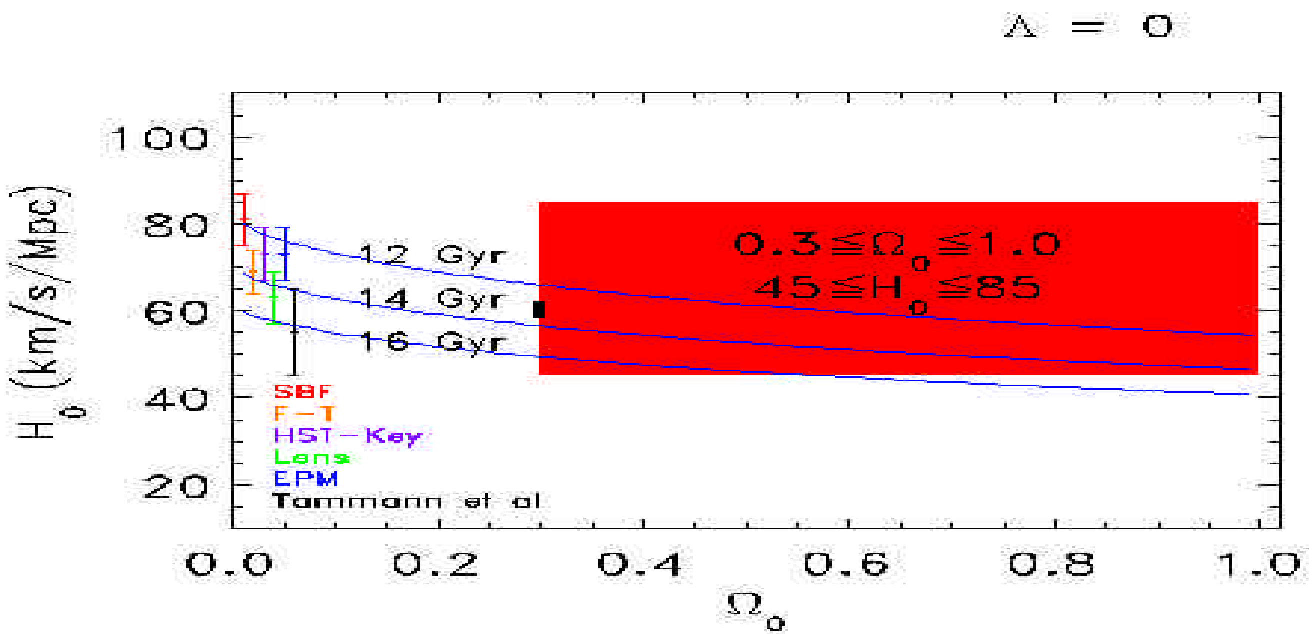
HOW MUCH BARYONIC (NORMAL) MATTER?



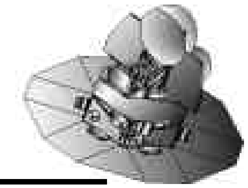
THE HUBBLE CONSTANT: EXPANSION RATE OF THE UNIVERSE



COSMOLOGICAL PARAMETER DETERMINATION

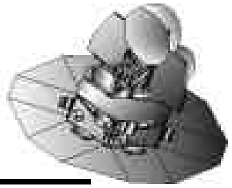


NOMINAL SCIENCE MISSION



- ***map*** of cosmic microwave background temperature
  - >95% sky coverage
  - angular resolution <0.3°
  - polarization sensitive
- rms sensitivity of 20 μK for 0.3°x 0.3° pixels
- rms systematic errors < 4.5 μK
- rms calibration accuracy <1% (from sky observations)

MINIMUM SCIENCE MISSION



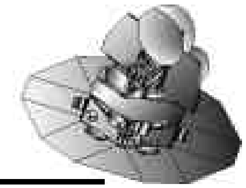
- Science Definition
  - determine cosmological parameters to:

    5% (Baseline Mission)

    20% (Minimum Science Mission)

- Engineering Definition
  - reduction of sensitivity at any or all frequencies
  - reduction in number of frequencies from 5 to no fewer than 3

- Two Examples
  - all radiometer sensitivities degraded by a factor of 1.8
  - all 90 GHz radiometers eliminated



SYSTEMATIC ERRORS

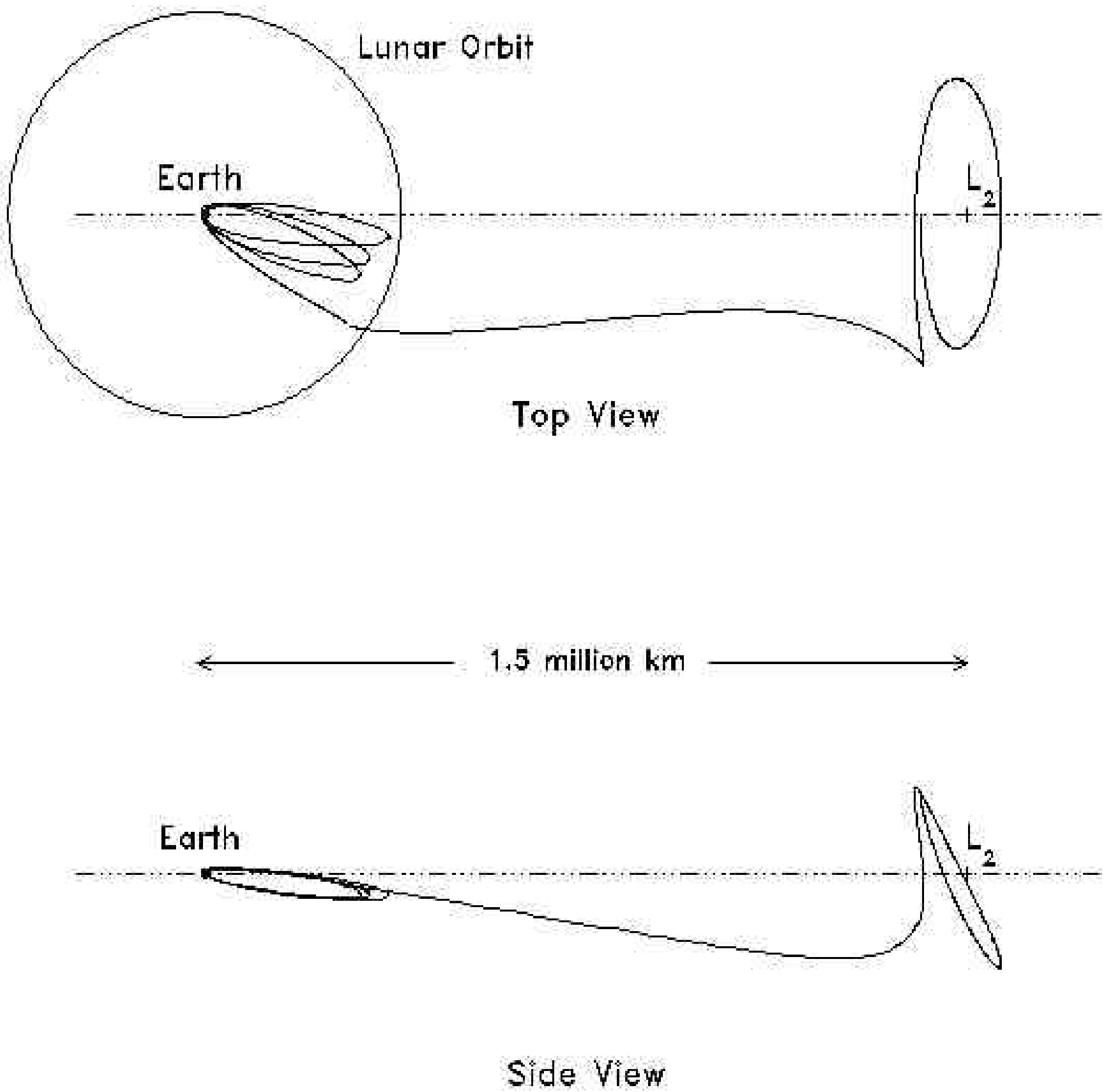
[Any signals, other than noise, that contaminate the part-in-a-million cosmic measurement]

- Minimize sensitivity of experiment to non-sky signals
  - Minimize all observatory changes
    - L2 orbit; constant survey mode operations
    - minimize transmitter time; use make up heater
  - Symmetric, rapidly switched, differential radiometers
  - Rapid sky scanning (30% of sky per hour)

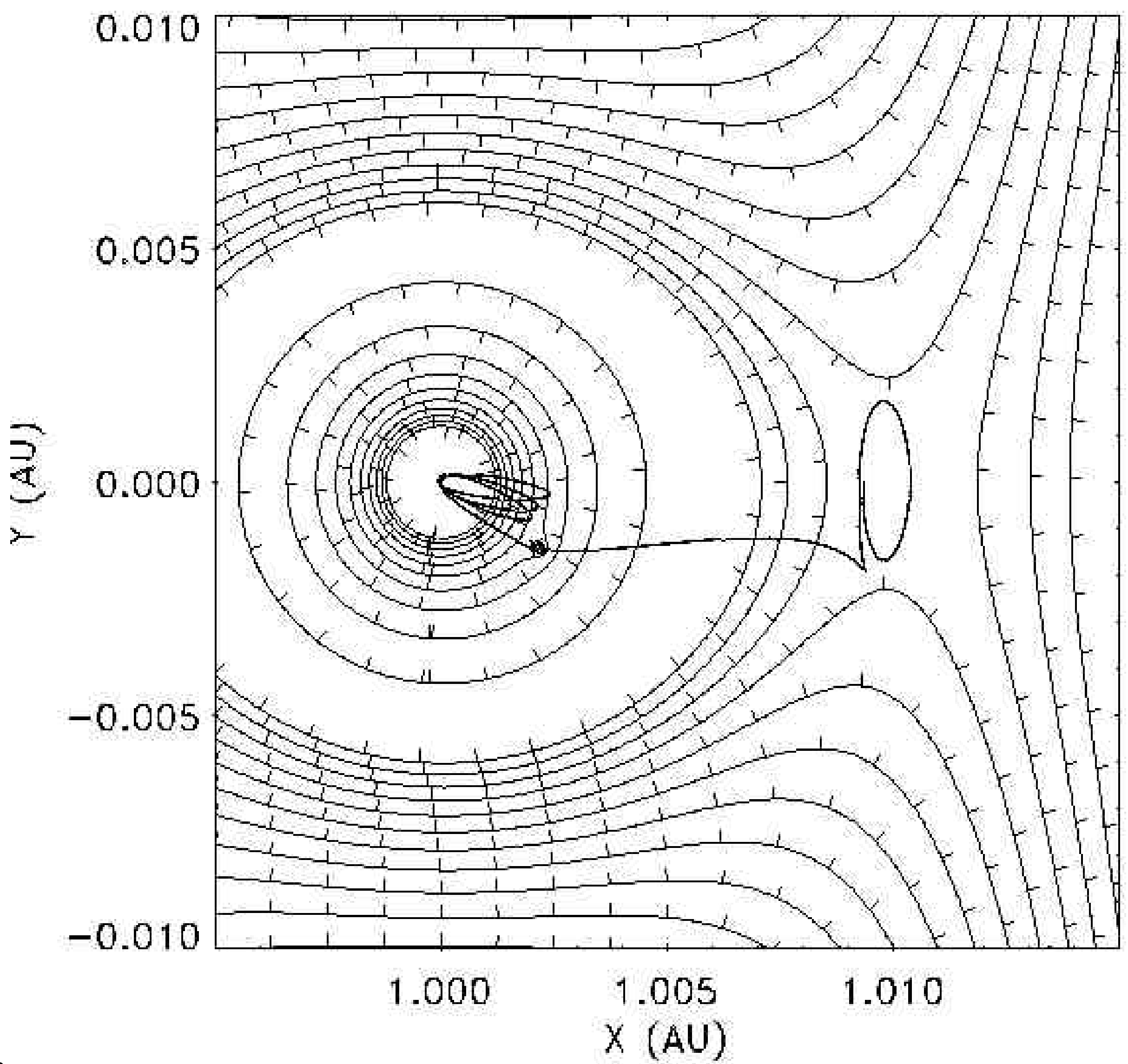
SPIN-SYNCHRONOUS NON-SKY SIGNALS ARE THE LEADING CONCERN

- Multiple modulation periods to isolate & identify systematic effects
  - switch (0.4 msec), spin (2 min), precess (1 hr), orbital (6 mo)
- Distinguish cosmic from non-cosmic sky signals
  - 5 frequencies to model and remove galactic signals
  - Minimize stray diffracted signals from Earth, Sun, Moon
    - large edge taper; diffraction shielding
    - L2 orbit

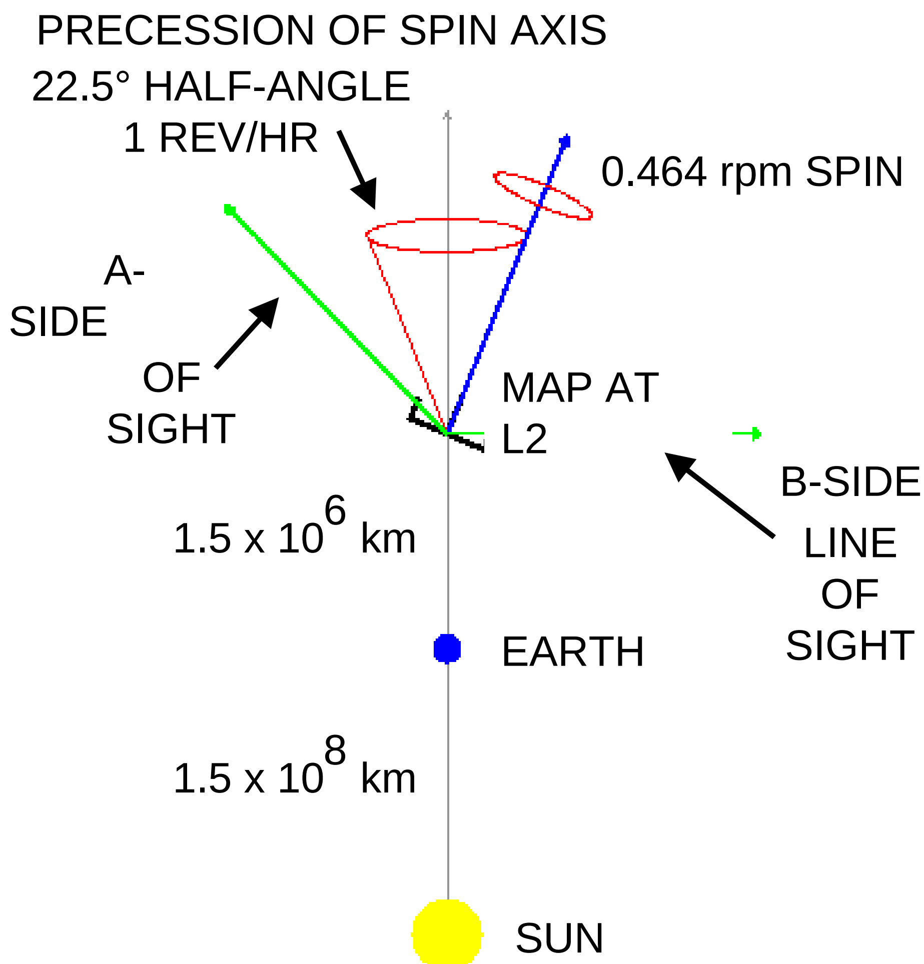
MAP TRAJECTORY TO L2

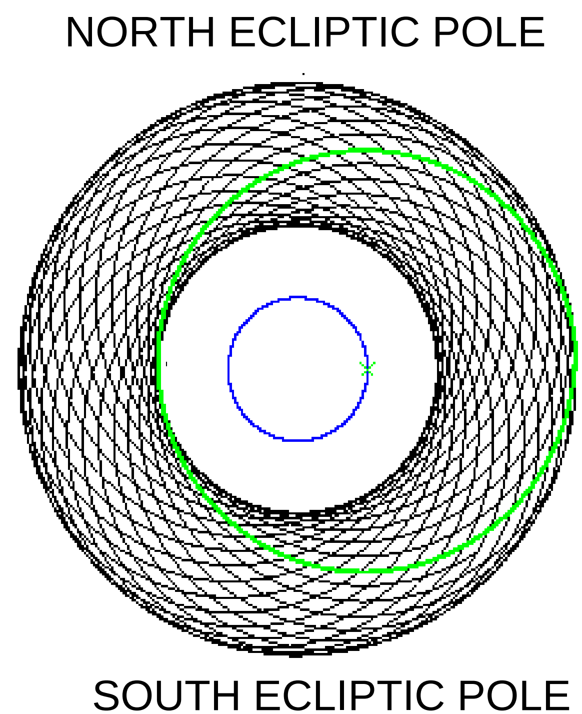


L2
GRAVITATIONAL POTENTIAL

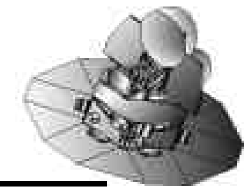


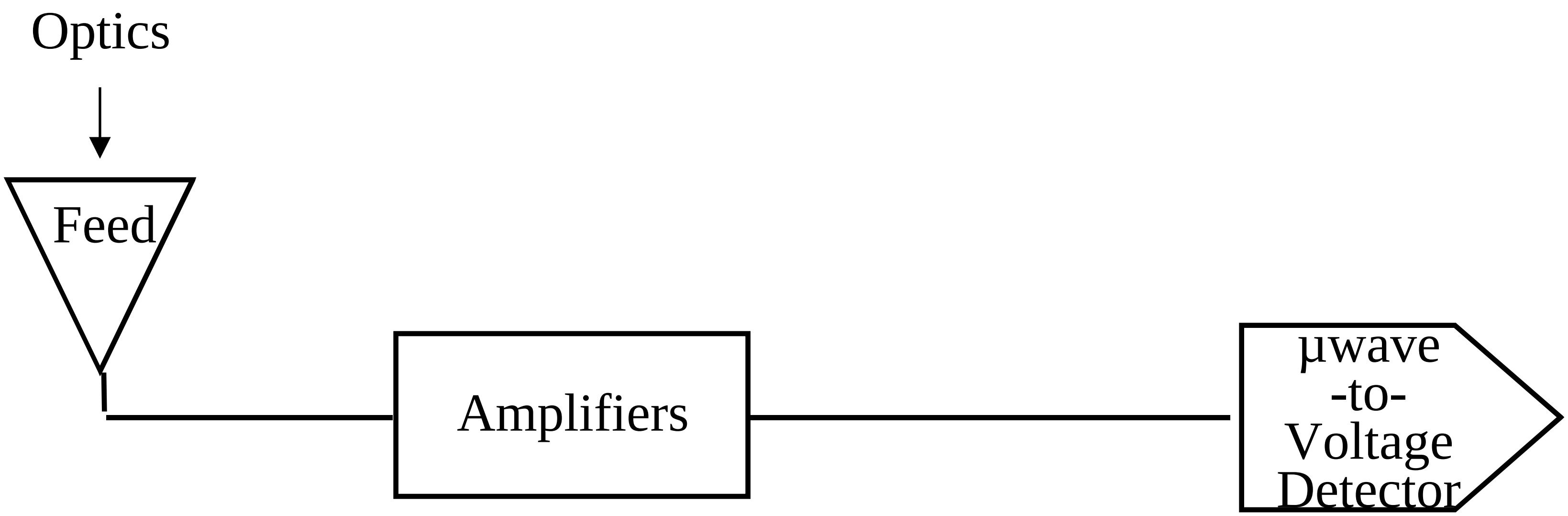
SPIN, PRECESSION & SKY COVERAGE





TOTAL POWER RADIOMETER



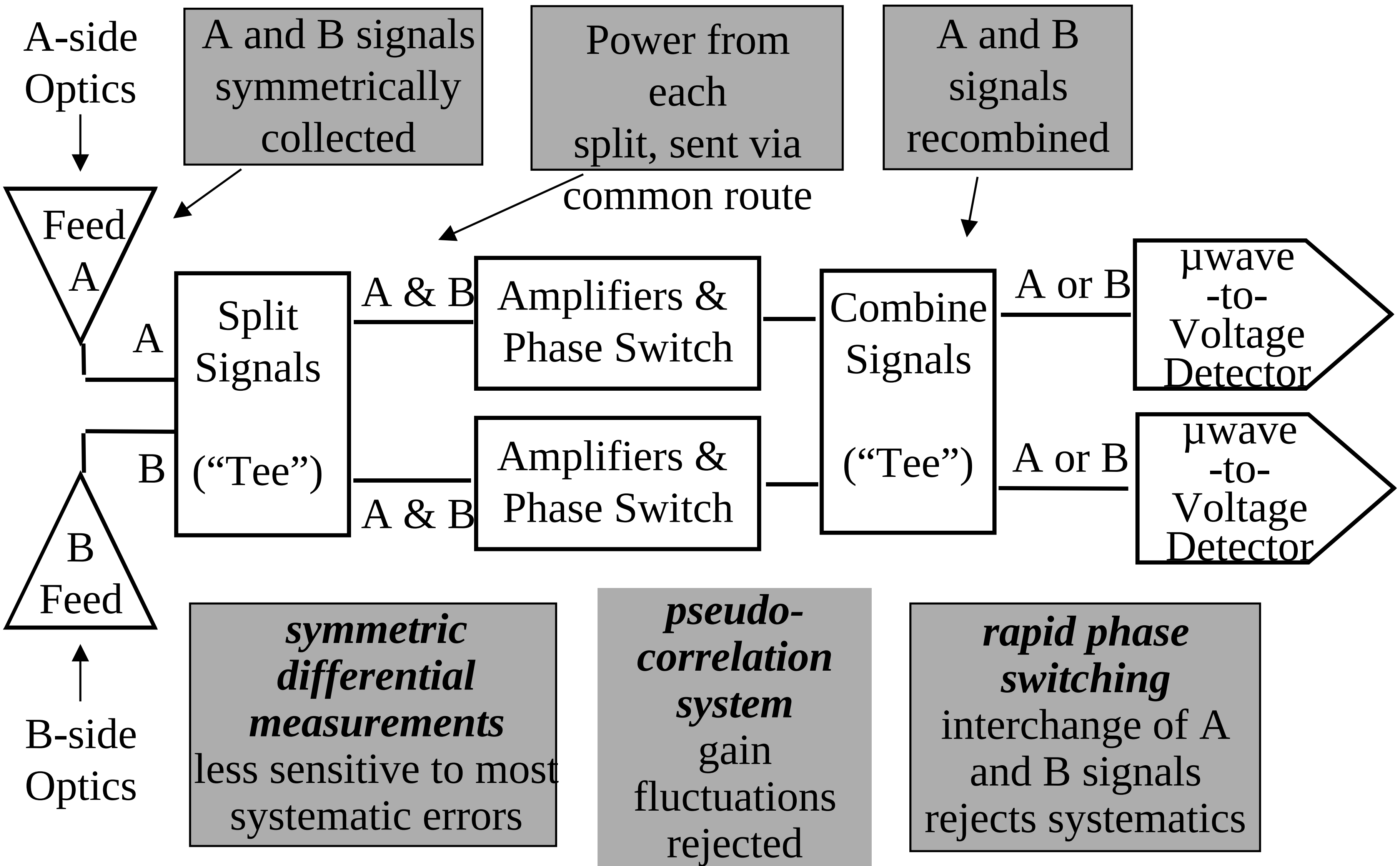


any changes in temperature, diffracted signals, etc. feed directly through the system

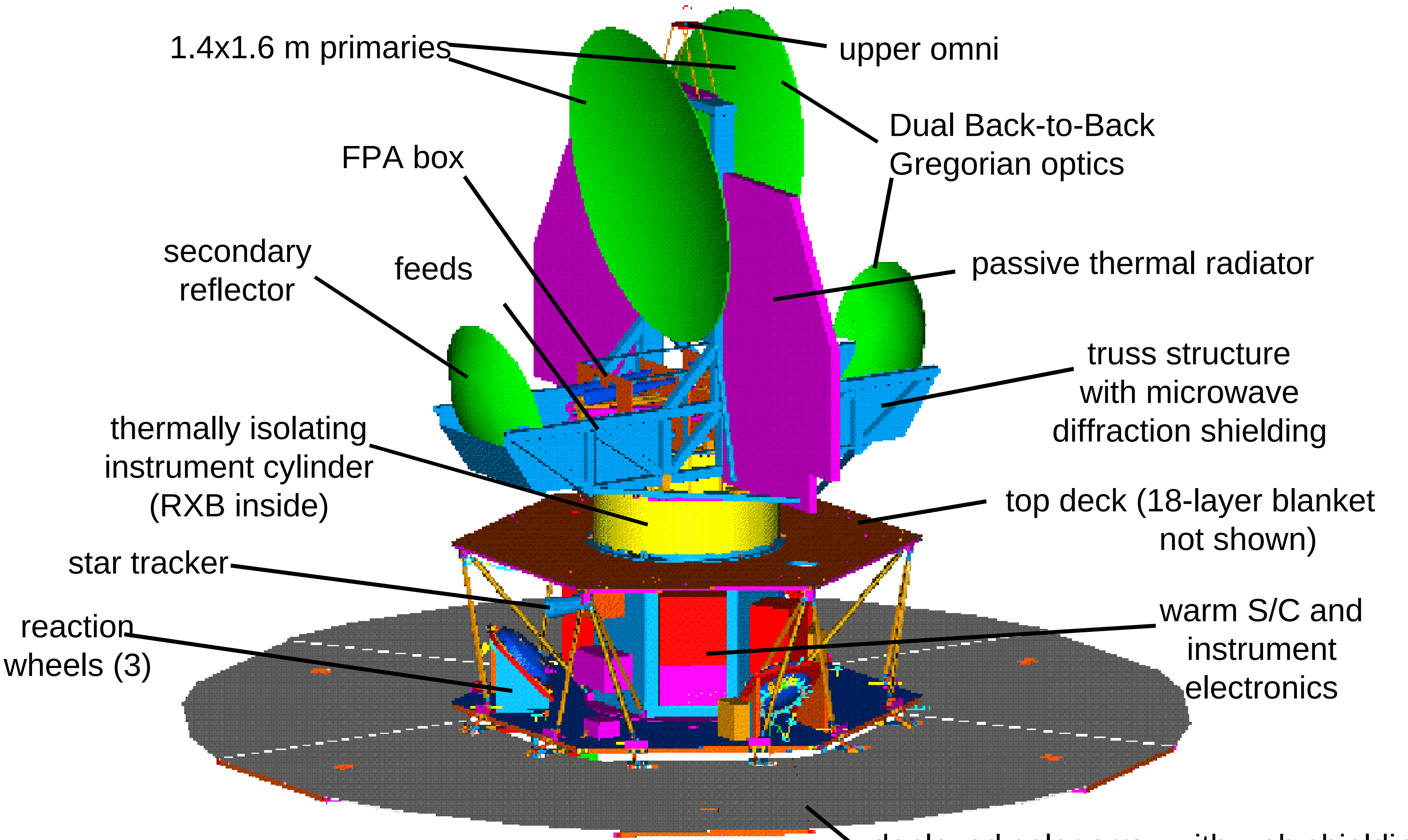
all instabilities (e.g. gain fluctuations) directly modulate the signal

lack of switching/modulation difficult to assess systematic errors

DIFFERENTIAL PSEUDO-CORRELATION RADIOMETER



MAP OBSERVATORY



National Academy of Sciences Reiterates the Importance of MAP

ASTRONOMY

Follow Up on Findings, Panel Tells NASA

Eagerly awaited. The MAP mission will chart details of the microwave background radiation.

At the top of the list for the next 10 years or so, said the committee, is refining a map of the microwave background radiation. In the early 1990s, the Cosmic Background Explorer revealed tiny temperature variations in this uniform bath of microwaves—the imprint of primordial "seeds" that grew into great structures in today's universe. A finer scale map of these ripples would yield clues not just to structure formation but also to the density and makeup of the universe, Thaddeus and his colleagues say—implicitly nudging NASA to keep a planned satellite called the Microwave Anisotropy Probe (MAP) on track for its August 2000 launch.

its report in a
ish list of instru-
the areas of sci-
top priority in
"We picked the

"Eagerly awaited"

"At the top of the list... is refining a map of the microwave background"

"...nudging NASA to keep a planned satellite called the Microwave Anisotropy Probe (MAP) on track..."

348 SCIENCE • VOL. 276 • 18 APRIL 1997 • http://www.sciencemag.org

Science Data Management

Gary Hinshaw

Goddard Space Flight Center

Presentation Outline

- What is OMEGA?
- Overview of science data products
- Overview of science data flow

Role of OMEGA

- "OMEGA": ***O***ffice of the ***M***AP ***E***xperiment ***G***eneral ***A***rchive
- Data analysis only, no mission operations responsibility
- Develop and maintain MAP Science Data Archive during the life of the mission
- Write and maintain science data processing software
- Produce and verify calibrated sky maps and ancillary data
  - Analyze maps for systematic errors - the *heart* of the job
- Deliver calibrated and corrected maps and ancillary data to NSSDC for preservation and public dissemination

OMEGA Software Practices

- Production software is written in Fortran 90/95 and C
- Analysis/imaging software is written in IDL and Fortran 90
- Adapt/re-use COBE software as applicable
- Source code revision control is implemented with the GNU Revision Control System (rcs)
- Code shall be modular for ease of maintenance and debugging
- All routines shall have clearly defined interfaces/argument lists and will be amply commented.
- Codes will be built with the make utility using a common set of macro definitions to standardize program compilation.
- Code organization and documentation will be maintained on the internal MAP web site to facilitate developer access.

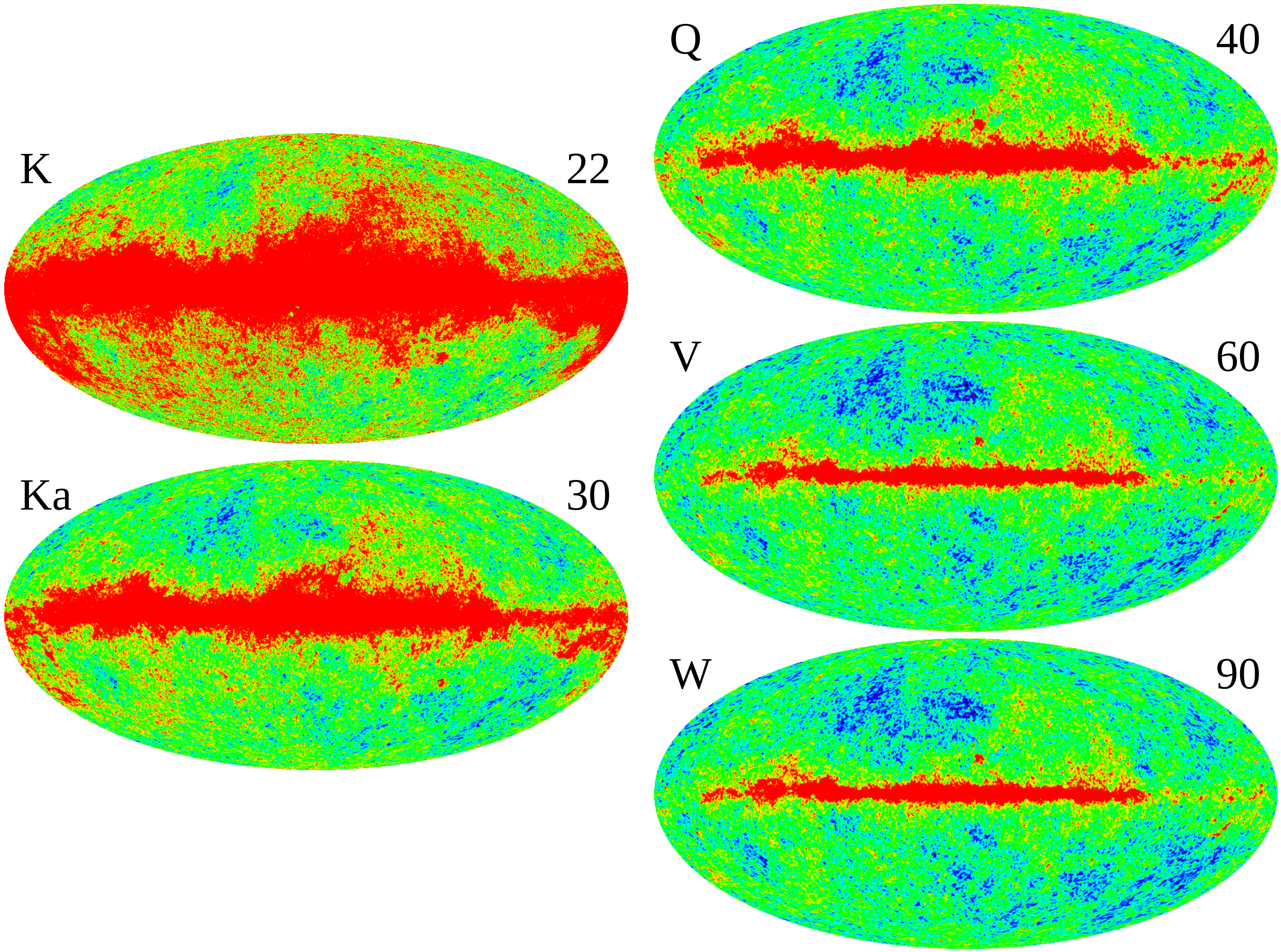
Survey Observations

- MAP will reach L2 approximately 3 months after launch.
- MAP commences science survey operations using combined spin and precession of spacecraft.
- No planning of routine science observations required.
- MAP achieves full sky coverage after 6 months of operation at L2.
- The six month data set provides the minimum ingredients with which to begin computing full sky maps:
  - Run the computer program that solves for sky map temperatures that are most consistent with the set of input temperature differences.
  - Analyze the resulting sky maps for systematic artifacts, develop necessary corrections and recompute the sky map.

Science Data Products

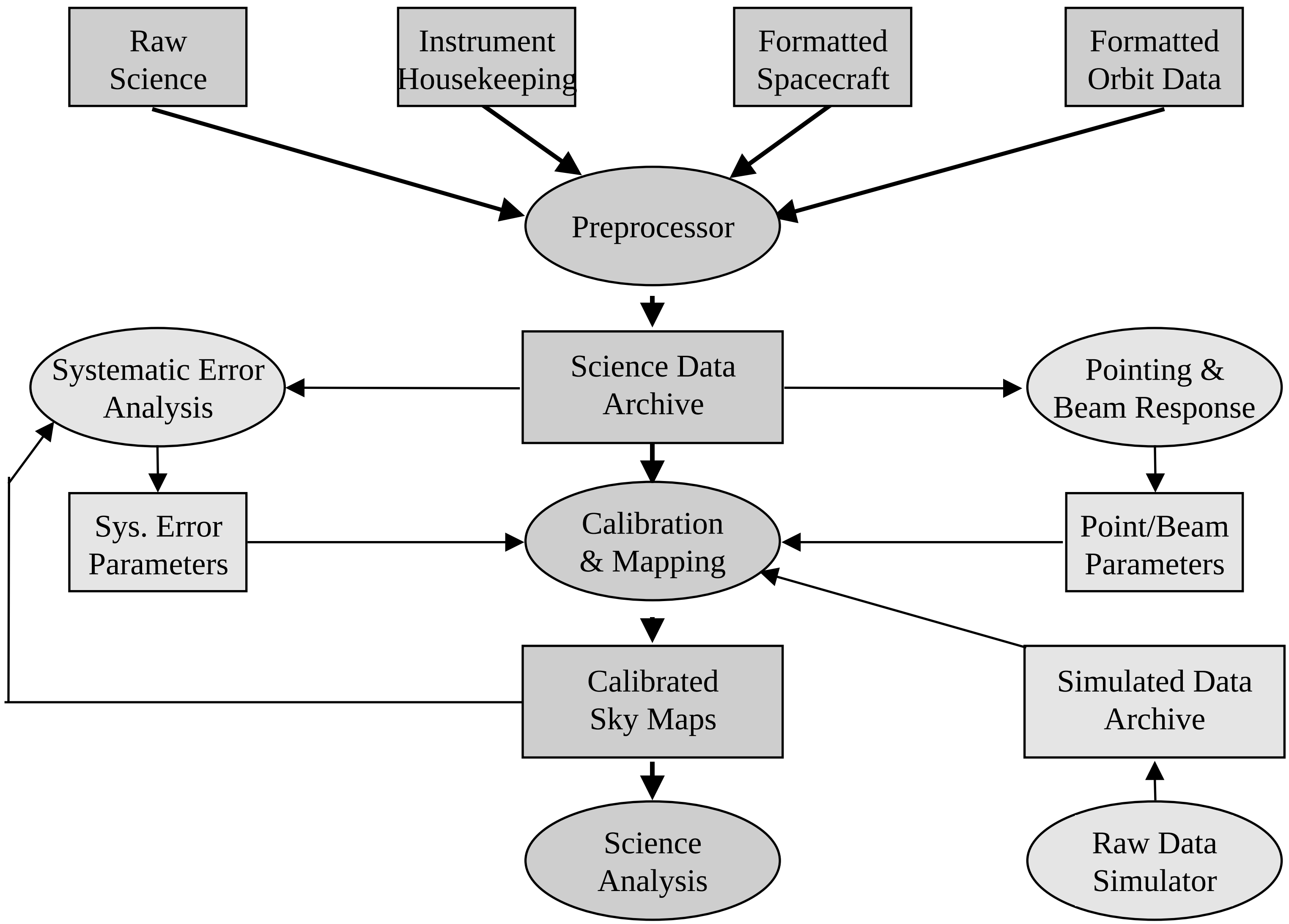
- 10 calibrated sky maps of CMB temperature anisotropy
  - 10 DAs: 1 @ 22 GHz (K), 1 @ 30 GHz (Ka), 2 @ 40 GHz (Q), 2 @ 60 GHz (V), 4 @ 90 GHz (W)
  - ~1-2 million pixels per map
- Master archive of temperature differences
  - ~35 GB of data per year
- Ancillary data sets for each differencing assembly
  - Beam response (“window function”)
  - Calibration and offset for each differencing assembly

MAP Frequency Coverage: 22 - 90 GHz



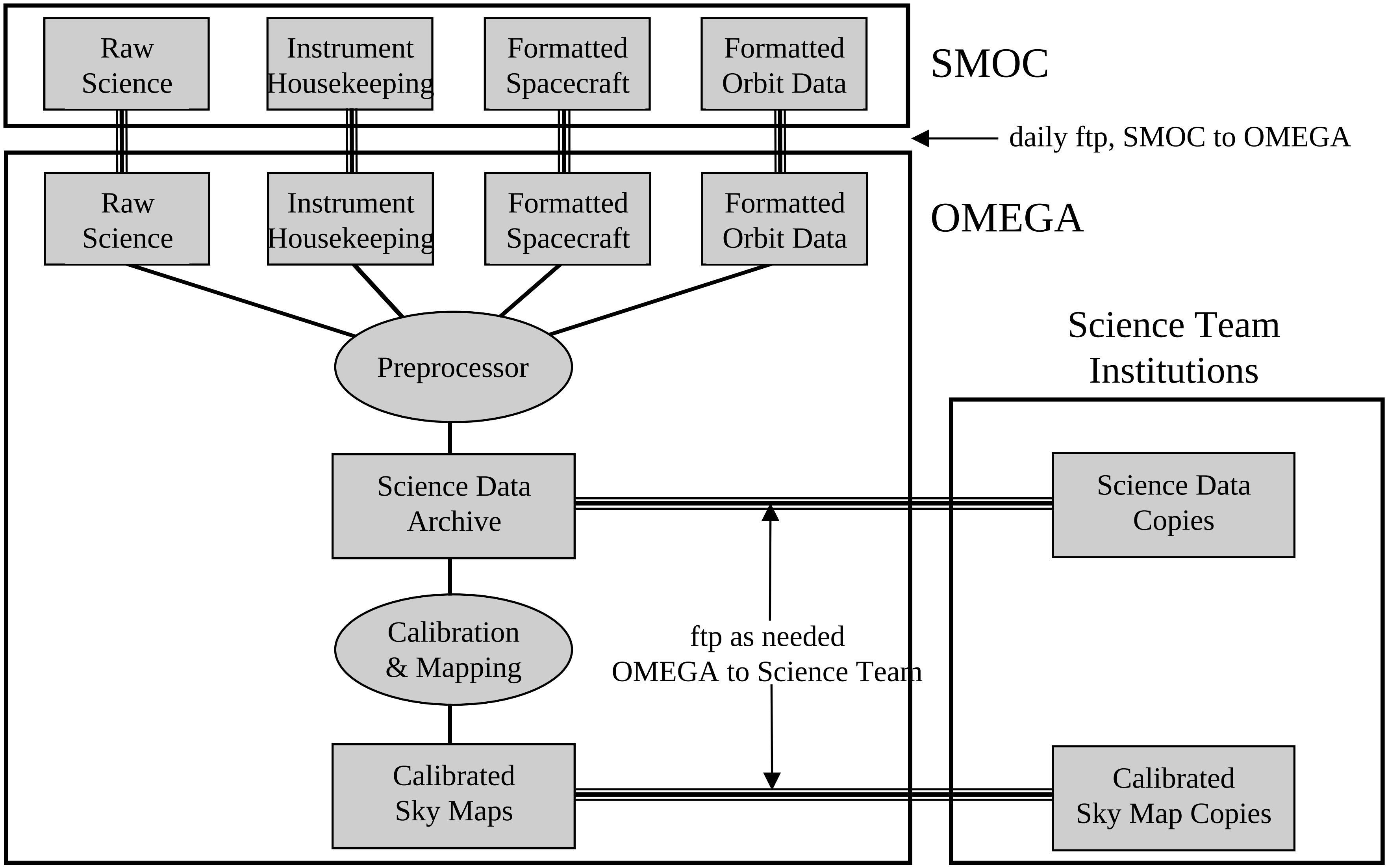
Science Data Pipeline - Overview

Science Data Management



Science Data Flow

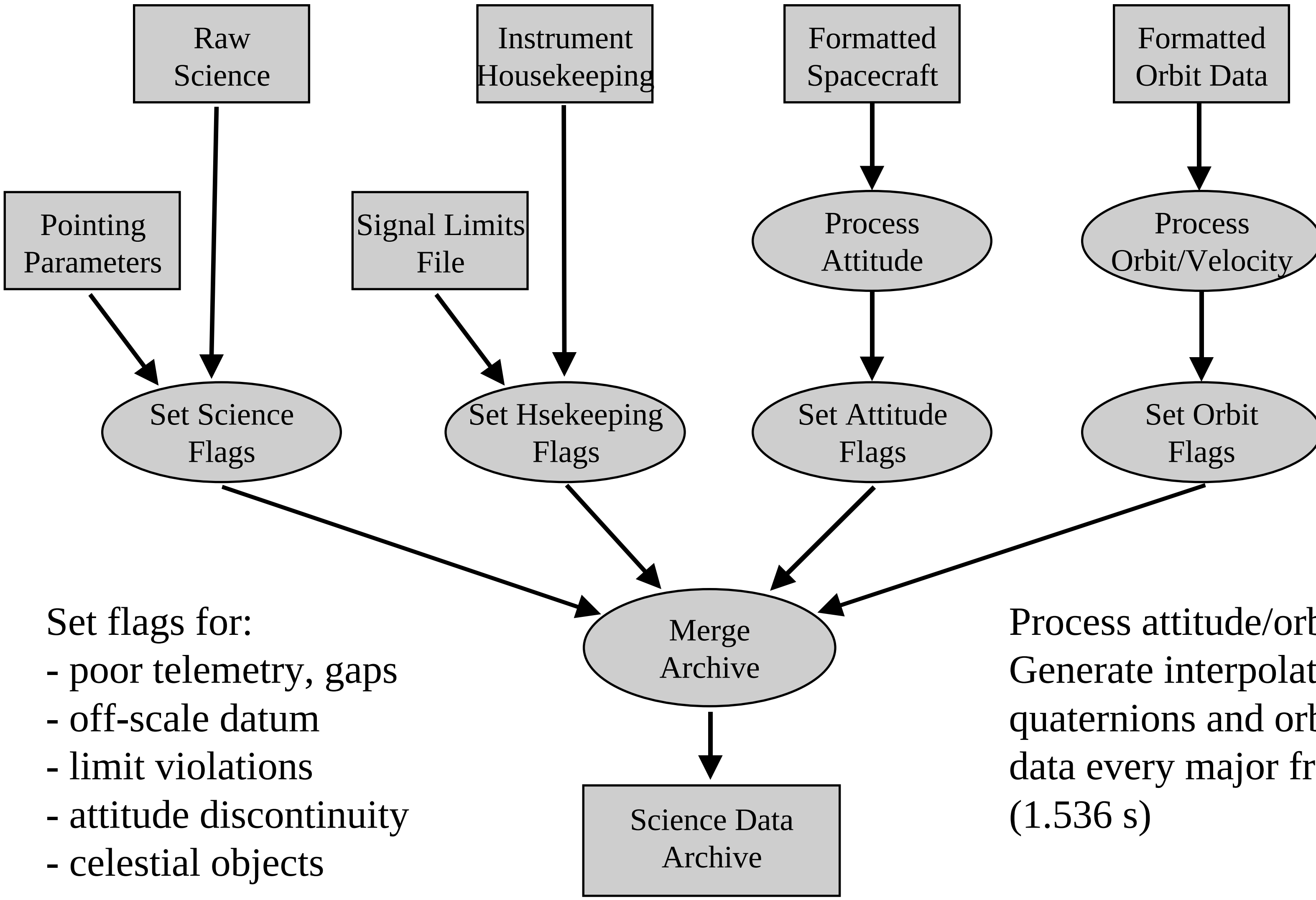
Science Data Management



MAP

Preprocessor - Detailed Flow

Science Data Management

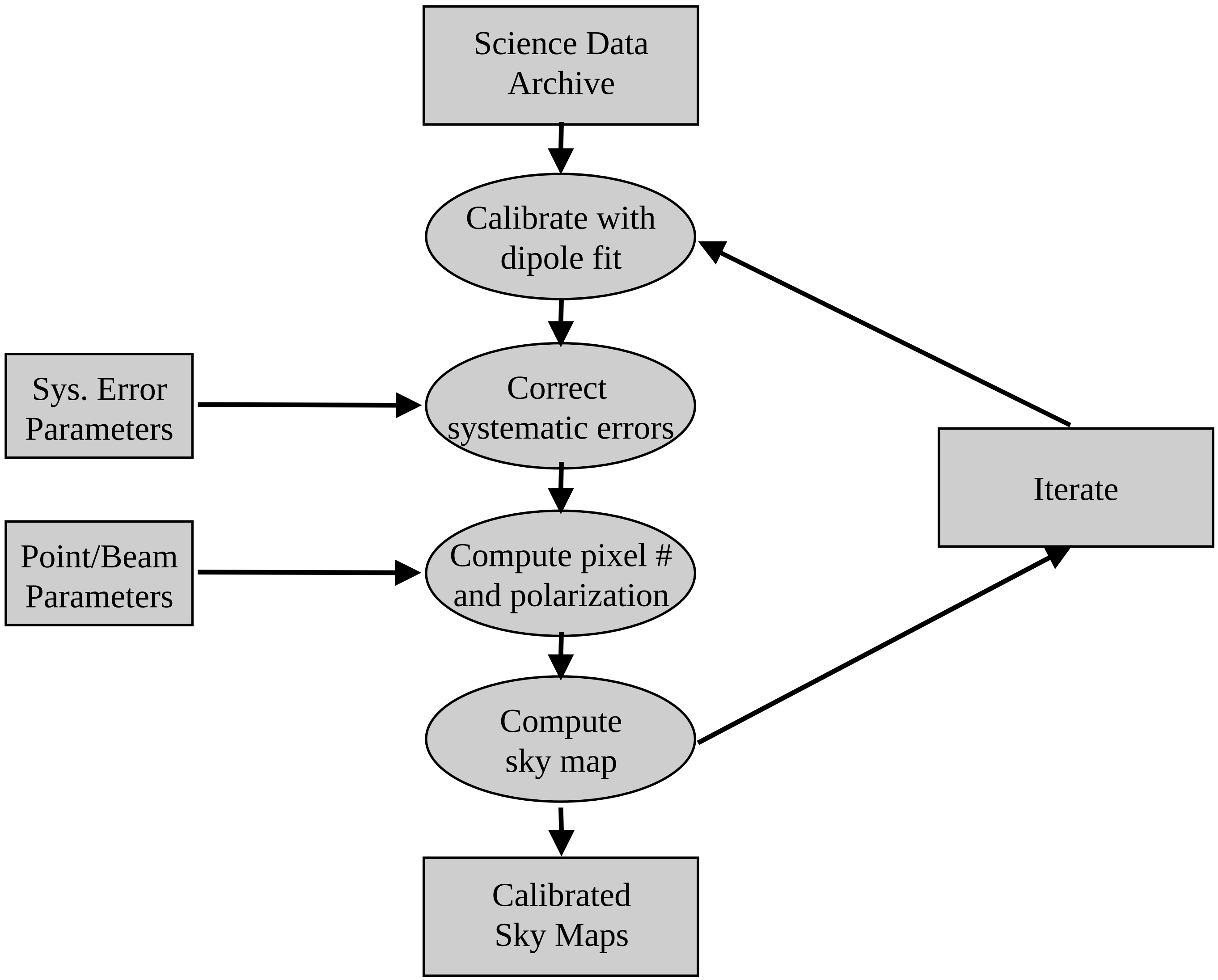


Set flags for:
- poor telemetry, gaps
- off-scale datum
- limit violations
- attitude discontinuity
- celestial objects

Process attitude/orbit: Generate interpolated quaternions and orbit data every major frame (1.536 s)

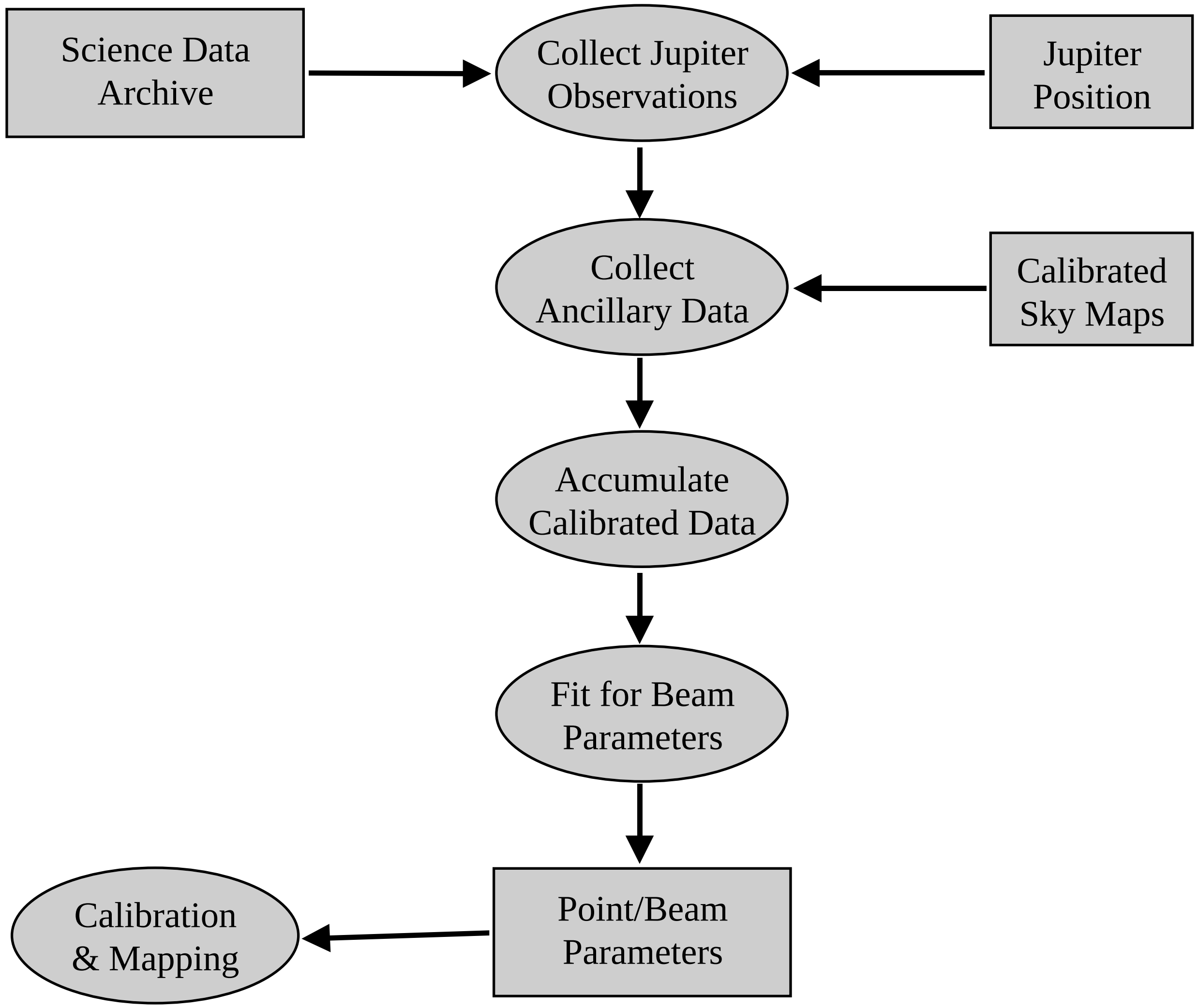
Calibration & Map Making - Detailed Flow

Science Data Management



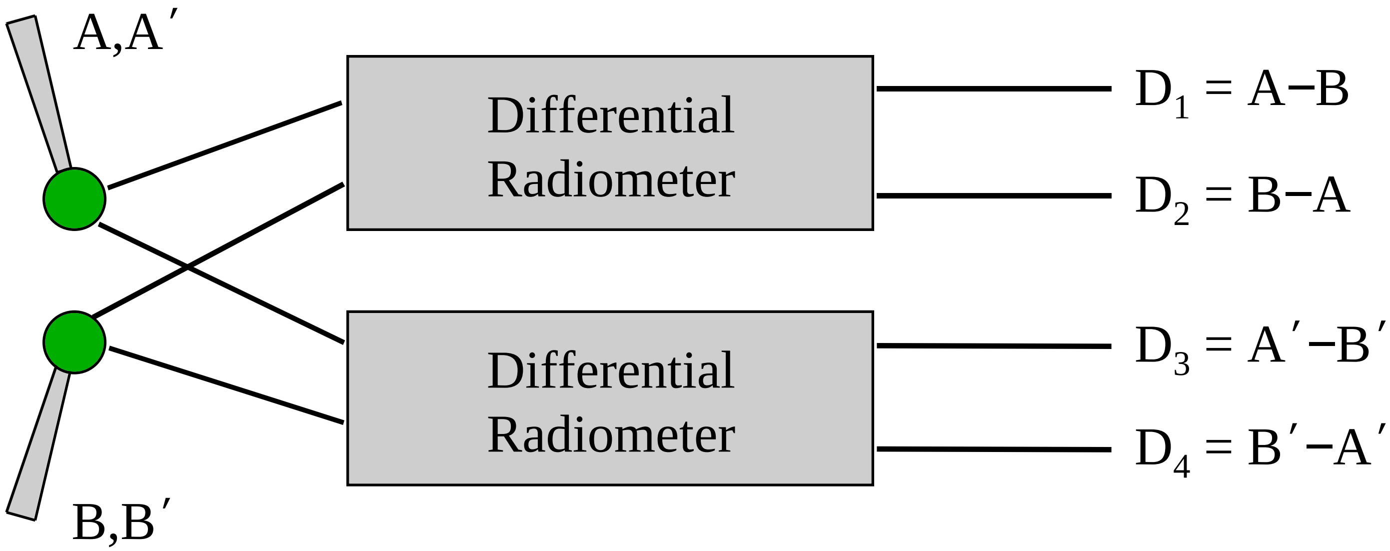
Pointing & Beam Analysis - Detailed Flow

Science Data Management



4-Channel Differencing Assembly

= Polarization splitter



[1 of 10 Differencing Assemblies (DAs)]

$$\Delta I \sim (D_1 - D_2) + (D_3 - D_4)$$

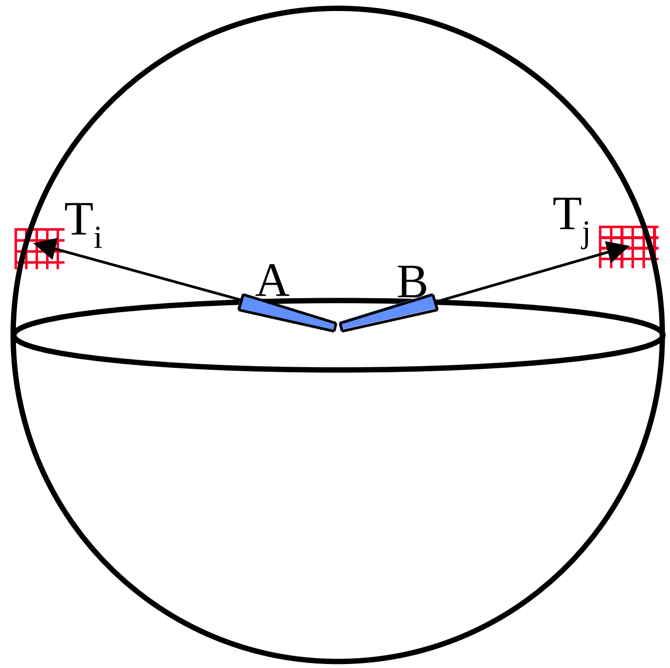
$$\Delta Q, \Delta U \sim (D_1 - D_2) - (D_3 - D_4)$$

Mapping with Differential Data

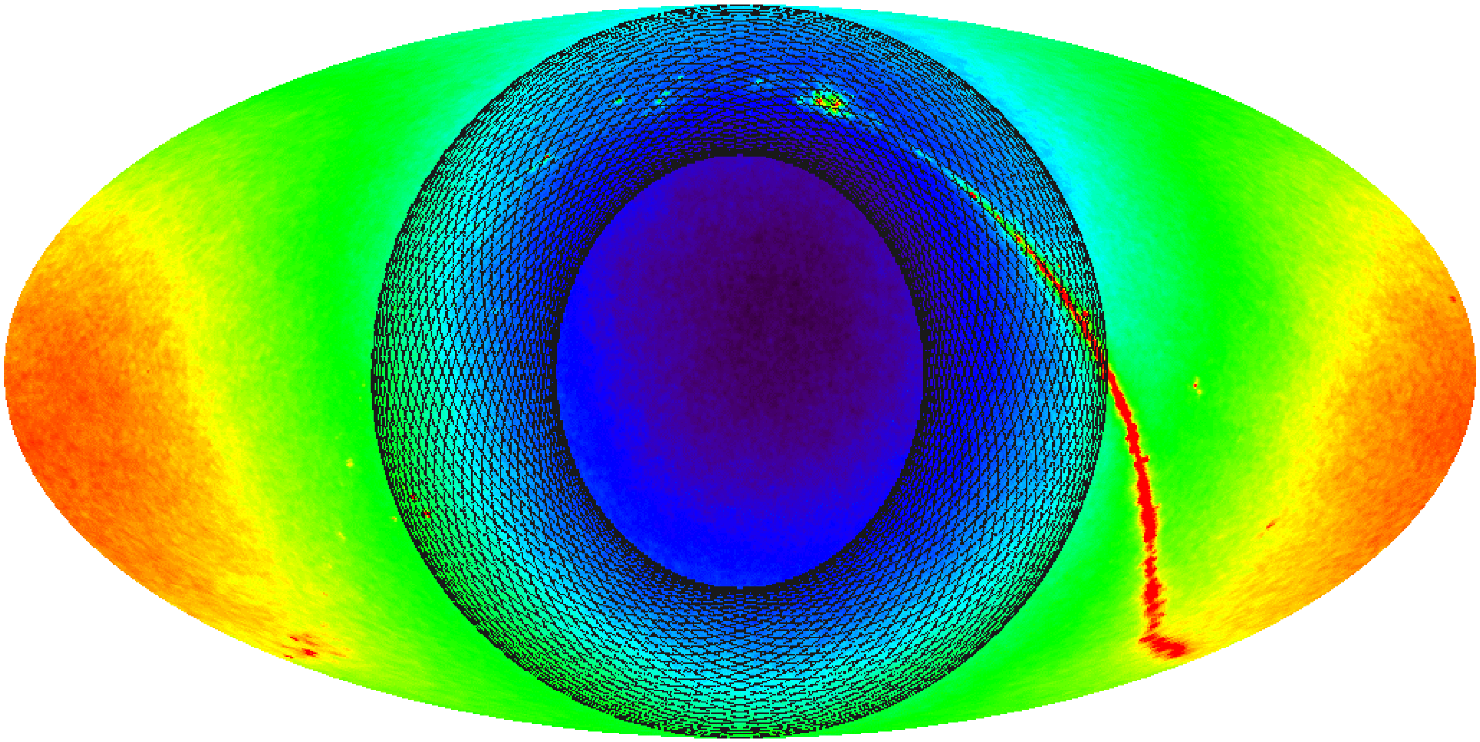
- The problem:
  - To produce a temperature map with 1-2 million pixels from a few billion temperature difference observations.
- The solution:
  - An iterative implementation of the least-squares fit used by COBE.
  - Wright, Hinshaw, & Bennett, Astrophysical Journal, 1996.
- The scheme:

$$\Delta T = T_i - T_j$$

$$T_i^{(n+1)} = \Delta T + T_j^{(n)}$$

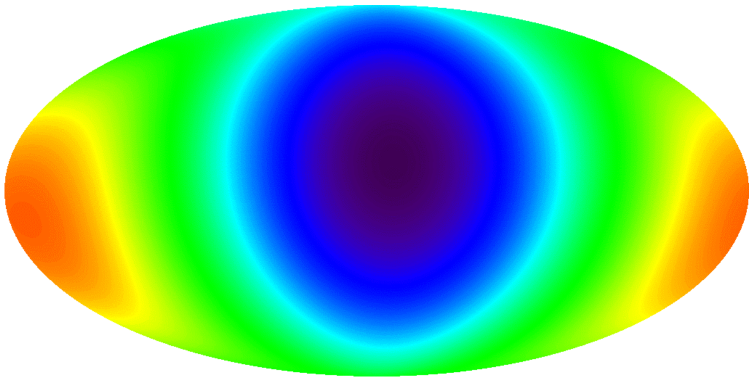


Model Sky Map with 1-hour Scan Pattern

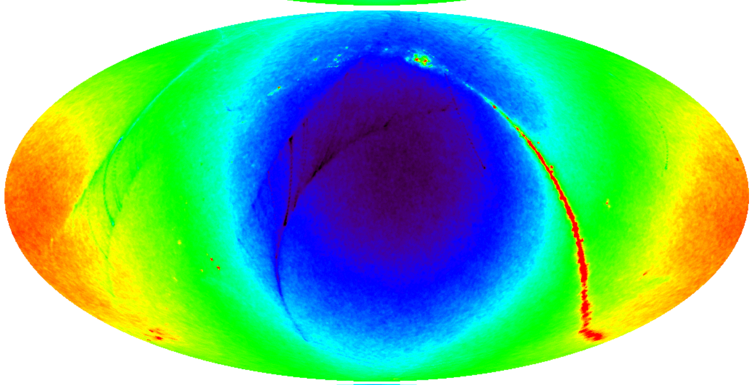


A and B lines-of-sight superposed on model sky map; one hour coverage, ecliptic coordinates

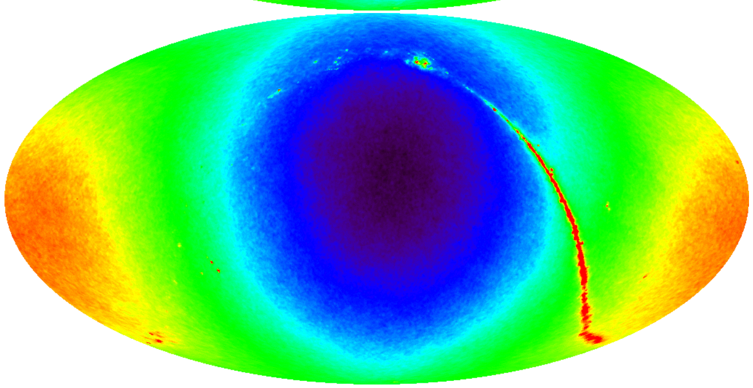
Recovered Intensity I_{out} - Iterations #0, 1, and 10



Initial guess of sky temperature:
$I^{(0)}$ = pure dipole

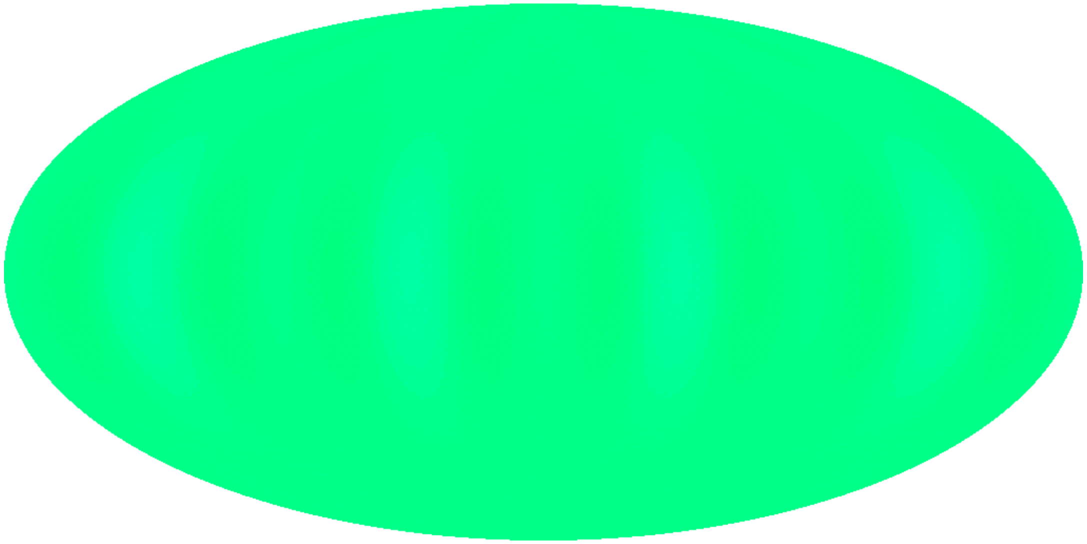


Response after 1 iteration - note spurious "Galaxy echos"



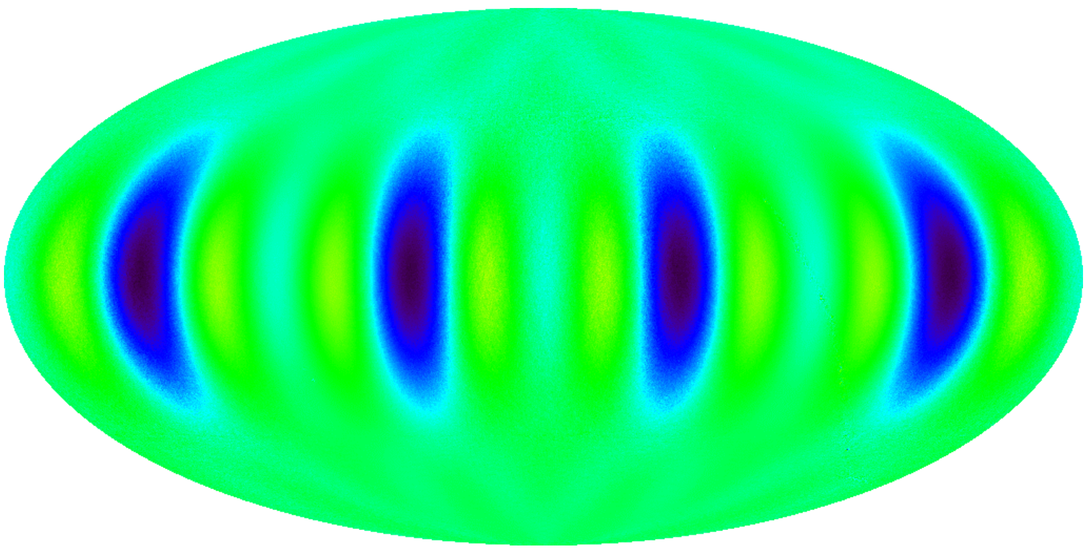
Response after 10 iterations - excellent convergence

Recovered Intensity I_{out} - Iteration #40



$\Delta I = I_{out}^{(40)} - I_{in}$

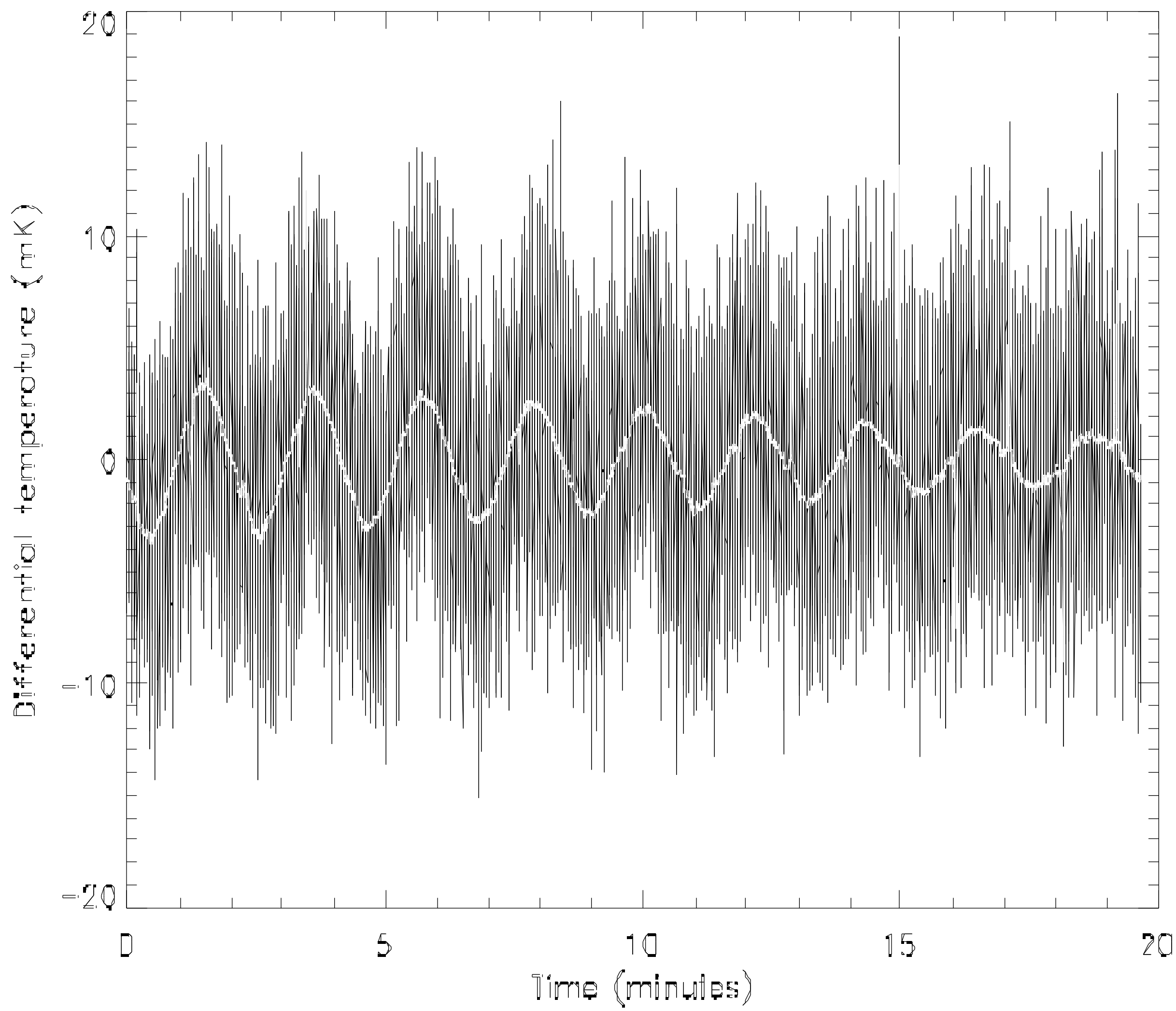
$\pm 5\ \mu K$



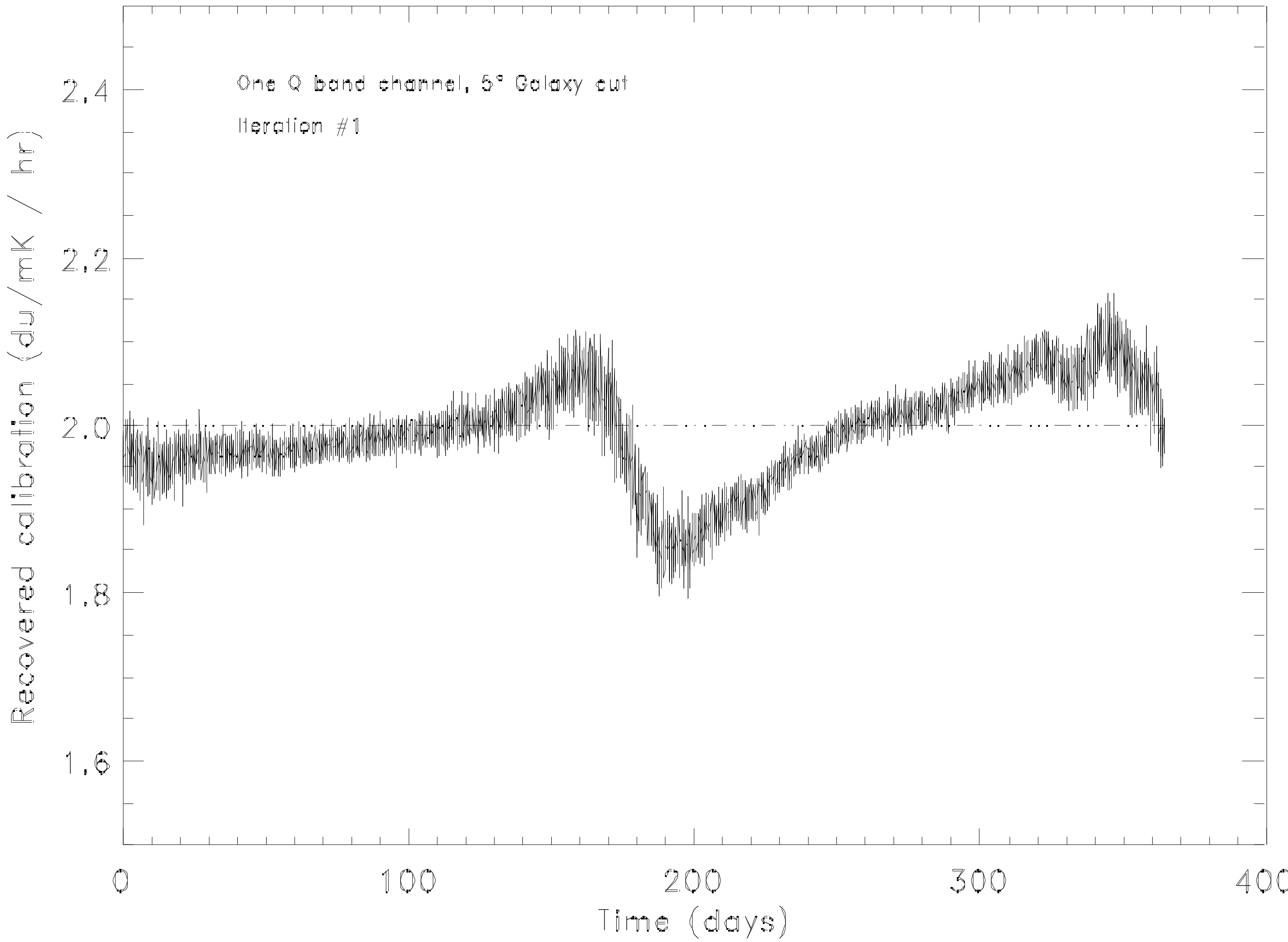
$\Delta I = I_{out}^{(40)} - I_{in}$

$\pm 0.2\ \mu K$

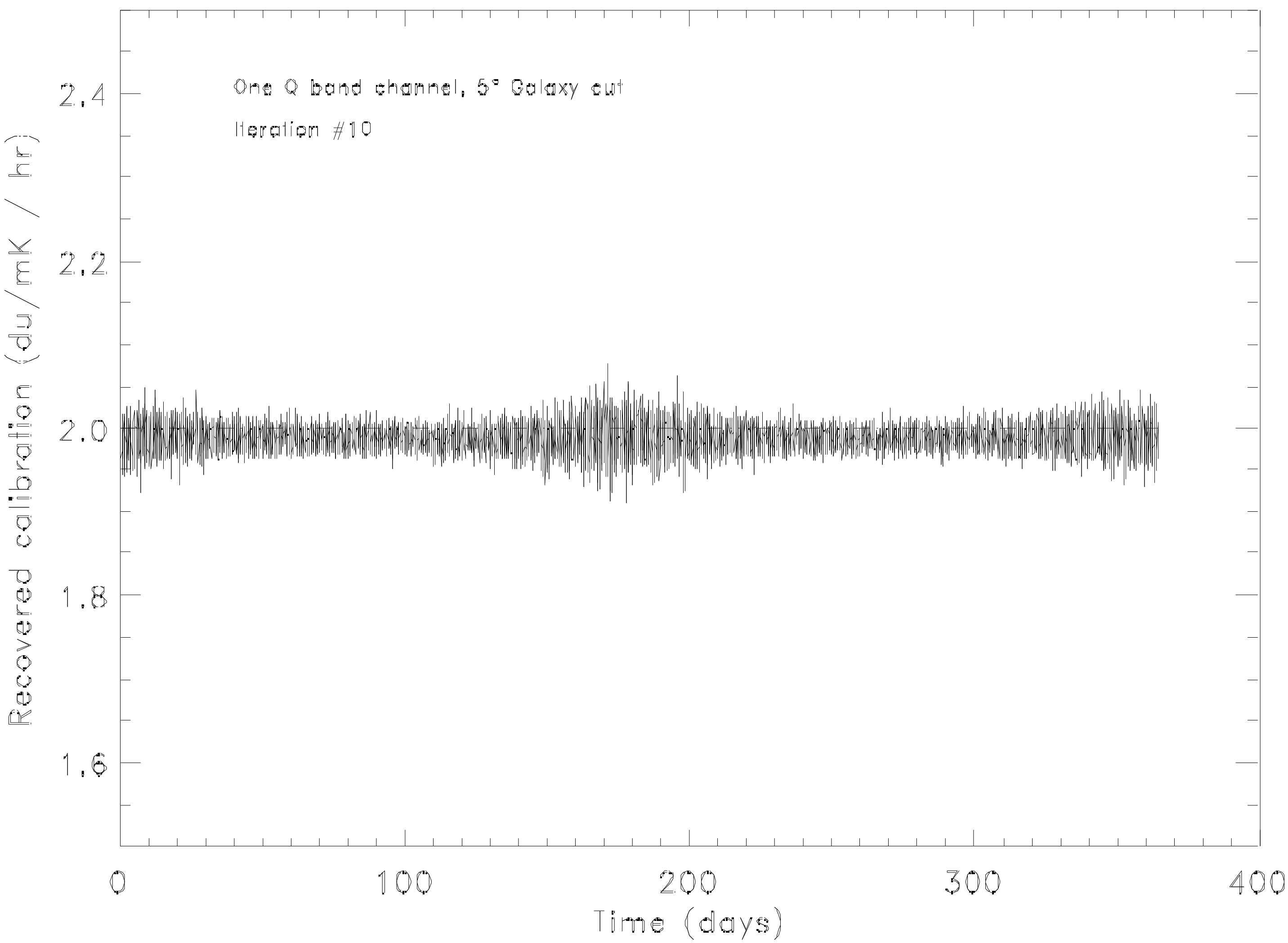
Simulated Differential Data - 20 minutes @ Q Band



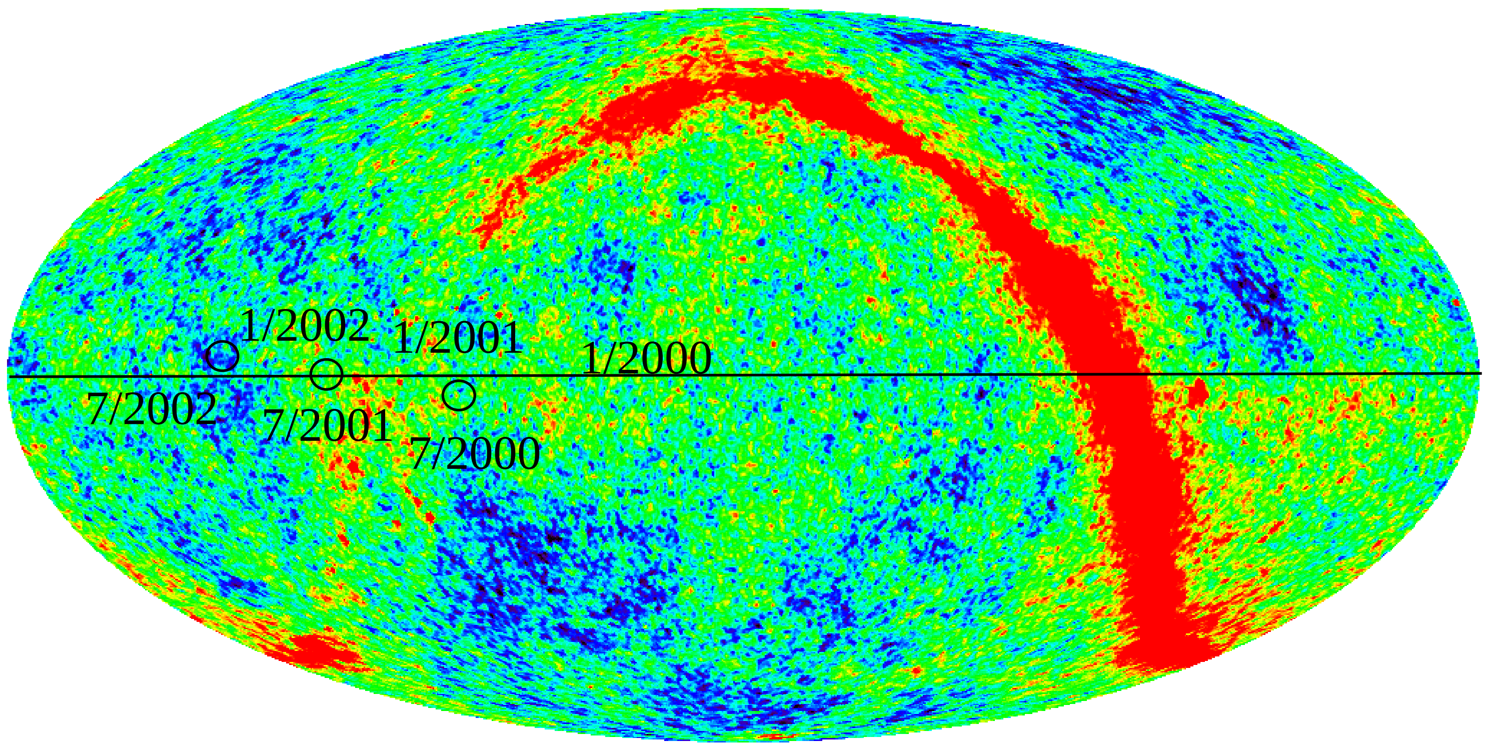
Calibration Recovery - Iteration #1



Calibration Recovery - Iteration #10

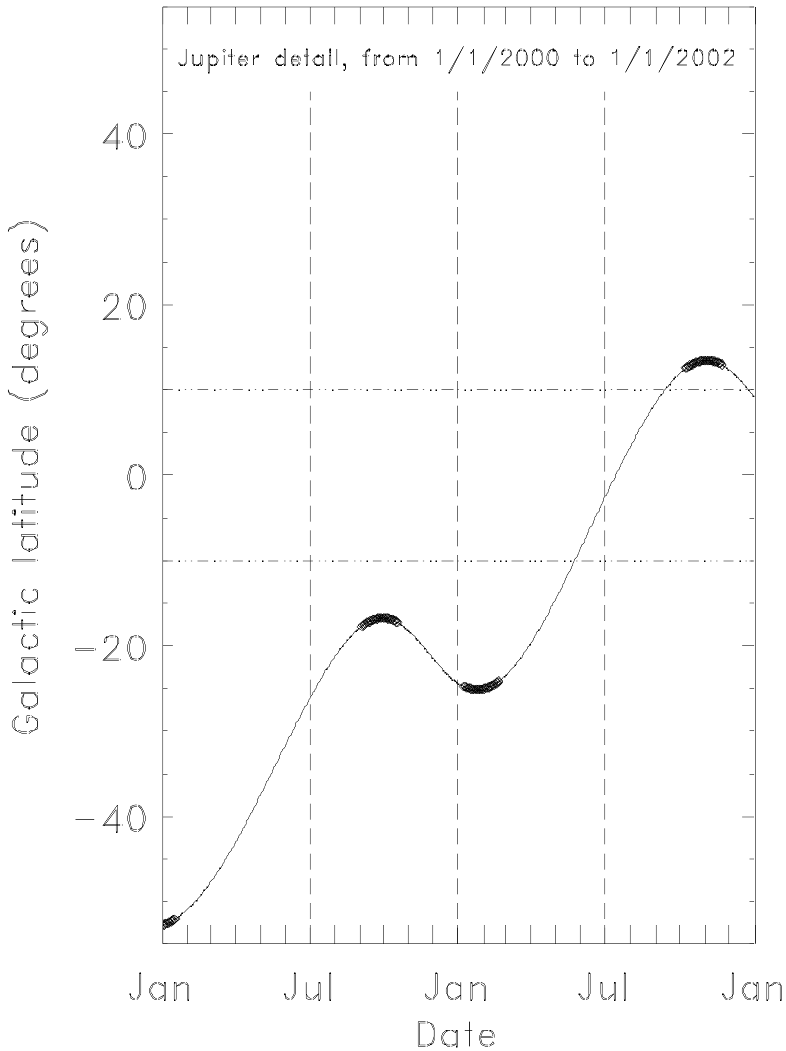


Model Sky Map with Jupiter Ephemeris



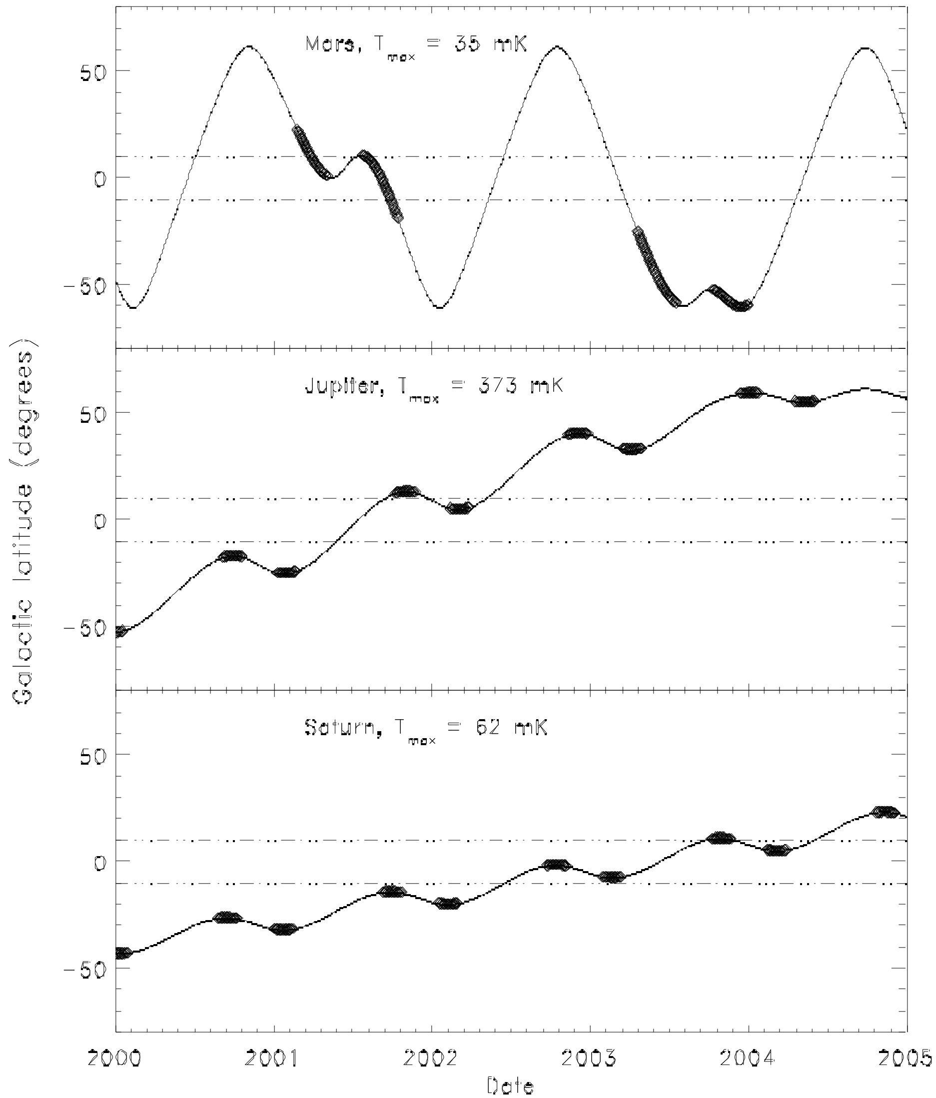
Position of Jupiter at 6 month intervals
superposed on model CMB sky; ecliptic coordinates

Jupiter Ephemeris - Detail



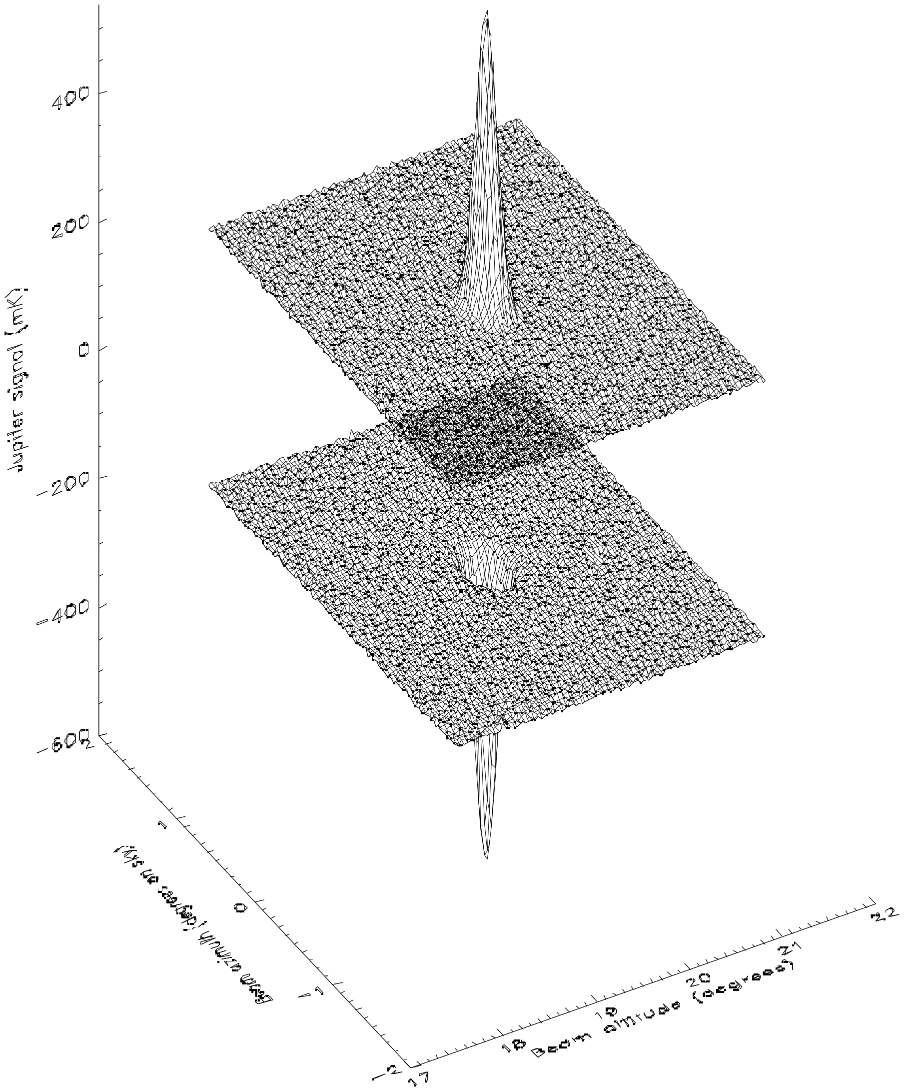
Bold indicates times when Jupiter is visible to MAP for beam mapping.

Planetary Ephemerides



Bold indicates times when the planets are visible to MAP for beam mapping.

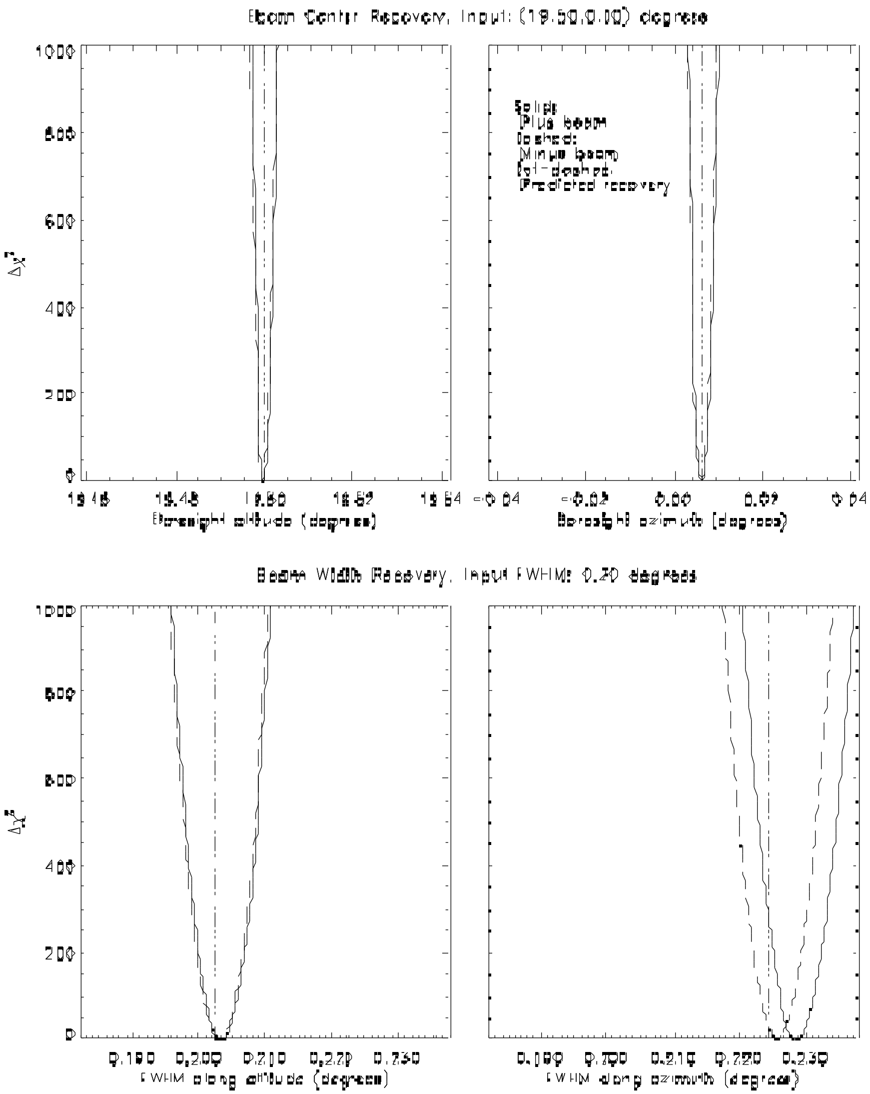
Beam Maps Compiled from Jupiter Observations



top: response of feed A to Jupiter signal, in spacecraft coordinates

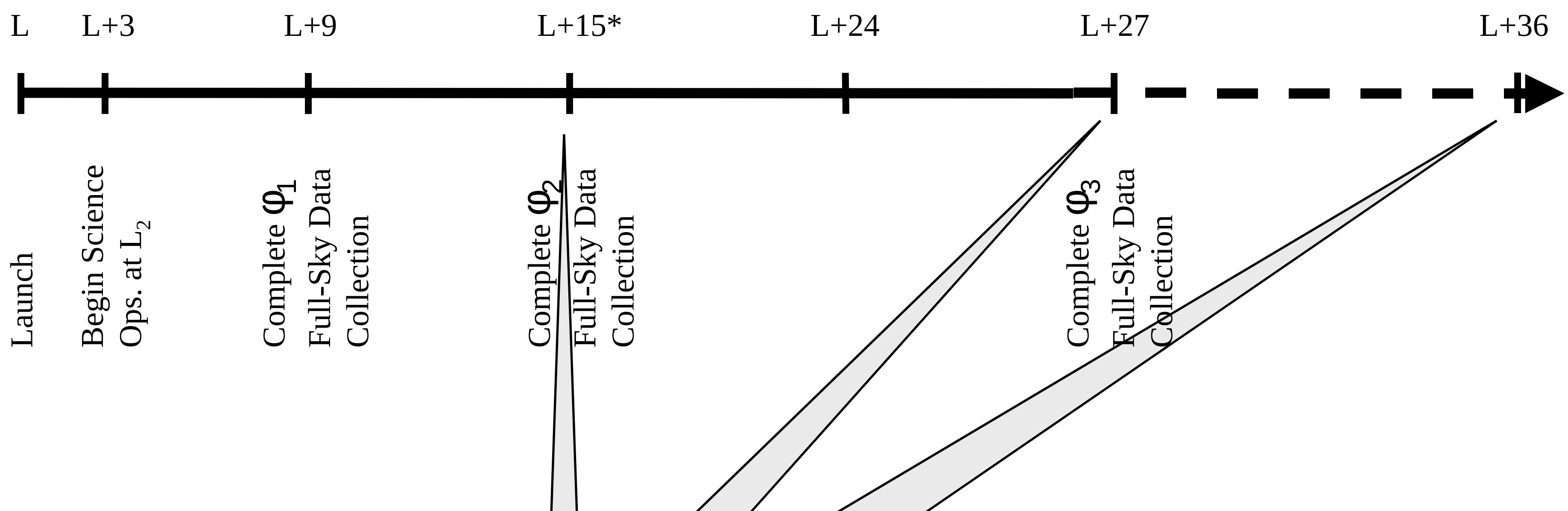
bottom: response of feed B to Jupiter signal, in spacecraft coordinates

Beam Parameter Recovery



MAP Data Timeline

Science Data Management



For each phase of data collection, φ_i:

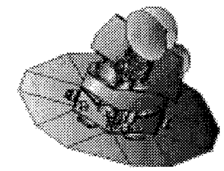
- Complete new full-sky map solution by simultaneously fitting many billion (!) temperature differences
- Complete analysis of instrument calibration and uncertainties
- Set upper limits on residual systematic contamination in the sky maps
- Deliver calibrated temperature anisotropy maps (1 from each of MAP's 10 data channels) with quantified random and systematic uncertainties

*Observations of the planet Jupiter are required in order to properly calibrate the instrument beam response. Because Jupiter is only visible during certain times of the year, this requirement could cause the completion of the first full-sky maps to be delayed by up to 3 months, depending on launch date.

Education and Outreach

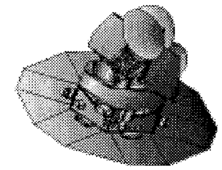
David Spergel
Princeton University

Outreach Strategy



- MAP will likely generate significant press coverage and public attention
  - COBE experience
- Pre-launch goal:
  - Develop quality educational material
- Post-launch goal:
  - Use publicity to broadly distribute educational material

MAP Outreach Efforts

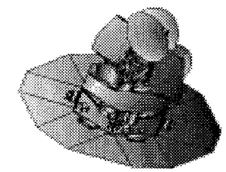


- Popular talks by MAP team members
- MAP world-wide-web pages
- Cooperative Science Learning Program (CSLP)
- Hayden Planetarium redesign
- Develop material (e.g., video clips) for the media

Popular Talks by MAP Team Members

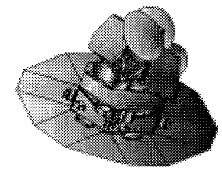
- Hayden Planetarium
- National Air and Space Museum
- Discovery Channel Space Update
- Princeton Plasma Physics Laboratory
  (“Science on Sundays”)
- Day with NASA program
- American Association of Physics Teachers
- School and club talks:
  - High, junior high, and elementary schools
  - Astronomy clubs

Classroom Demonstration



- Demonstration to illustrate importance of:
  - Differential Measurements
  - Systematic error Control
- Procedure
  - Take two students of nearly equal height
  - Have students measure their heights with one-foot rulers and compare
  - Discuss difficulties of absolute measurements and systematic errors
  - Next, make a differential measurement of students relative heights
  - Stress the link to MAP's differential measurements

MAP Web Pages

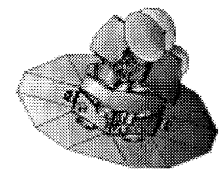


- Developed by
  - David Spergel, Brooke Simmons (PU)
  - Gary Hinshaw, Chuck Bennett (GSFC)
- More than 50 html pages and 100 images including:
  - "Introduction to Cosmology" pages
  - "Technical Information about MAP" pages
  - "Non-Technical Technical Information" pages
- Typical visitors:
  - Interested members of the public
  - Students working on term papers
  - Scientists working in cosmology

CSLP Program

- Links high schools with NASA missions
- Several Explorer programs already participating in CSLP
- Plan to attend August organizational meeting at NASA/ Lewis

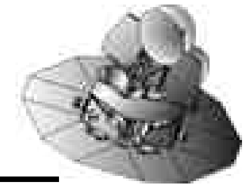
Hayden Planetarium



- Undergoing complete renovation - new building will open Fall 1999
- $130 million project
- Over 1 million visitors per year
- MAP team is providing cosmology information and scientific design guidance
- Centerpiece of planetarium: show featuring the cosmic microwave background and the Big Bang!

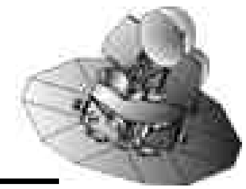
PROJECT OVERVIEW

AGENDA



- WORK BREAKDOWN STRUCTURE
- ACQUISITION STRATEGY
- ROLES AND RESPONSIBILITIES
- RELIABILITY POLICY
- DESIGN REVIEW PROGRAM
- SCHEDULE
- EXPLORERS TECHNOLOGY INITIATIVE

WORK BREAKDOWN STRUCTURE



MAP MISSION UPN 287-1

PROJECT MANAGEMENT 287-11
- -1 Science Team & Science Support
- -2 Plan, Org, Implemen. & Control
- -3 Education & Public Outreach

SYSTEM ENGINEERING 287-12
- -1 Sys-level Analytical Integ.
- -2 Mission System Engr.

PERFORMANCE ASSURANCE 287-13
- -1 Parts Engineering
- -2 Materials Engr.
- -3 Quality Assurance
- -4 Safety & Reliability

"SPACECRAFT" SUBSYSTEMS 287-14
- -1 Attitude Control
- -2 Command & Data Handling
- -3 Power
- -4 Communications
- -5 Electrical Interconnection
- -6 Structural/Thermal
- -7 Flight Software
- -8 (intentionally blank)
- -9 "Spacecraft" I&T

"INSTRUMENT" SUBSYSTEMS 287-15
- -1 Structural/Thermal
- -2 Spacecraft Mission Uniques
- -3 Electronics
- -4 Thermal Reflector System
- -5 (intentionally blank)
- -6 "Instrument I&T
- -7 Differencing Assemblies

GROUND SEGMENT 287-16
- -1 Development
- -2 I&T Systems
- -3 Science/Mission Operations Center

SYSTEM INTEG. I&T 287-17
- -1 Integration & Perf. Testing
- -2 Environmental Testing
- -3 Transport Operation
- -4 Launch Site Operations
- -5 Integrated Vehicle Operations
- -6 Launch & In-Orbit Checkout

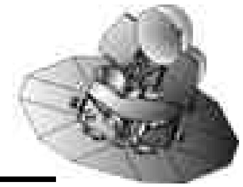
LAUNCH VEHICLE 287-18
- -1 Basic
- -2 Mission Uniques
- -3 Aircraft Coverage

MISSION OPS & DATA ANALYSIS 287-19
- -1 Ops. Preparations
- -2 Flight Operations
- -3 Office of the MAP Exp. Gen. Archive
- -4 Data Analysis Preparations
- -5 Flight Software Maintenance
- -6 Ground Segment Maintenance
- -7 Network Operations

CONTINGENCY 287-10
- -1 Technical Margin
- -2 Schedule Margin

RMD 5/6/97

RESPONSIBILITY BY INSTITUTION



GODDARD

- PROJECT MANAGEMENT
- SYSTEMS ENGINEERING
- INTEGRATION AND TEST
- PERFORMANCE ASSURANCE
- STRUCTURE/THERMAL
- INSTRUMENT ELECTRONICS
- SPACECRAFT SUBSYSTEMS
- GROUND SYSTEM
- SCIENCE/MISSION OPS
- SCIENCE/DATA ANALYSIS
- DATA ARCHIVING

CHICAGO

- SWG CHAIR
- SYSTEM ENG/I&T SUPPORT
- SCIENCE/DATA ANALYSIS

PRINCETON

- INSTRUMENT SCIENTIST
- DIFFERENCING ASSEMBLIES
- REFLECTOR DESIGN & TEST
- MICROWAVE FEEDS
- SYSTEM ENG/I&T SUPPORT
- SCIENCE/DATA ANALYSIS
- EDUCATION AND PUBLIC OUTREACH COORDINATOR

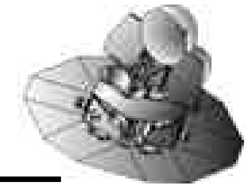
UCLA

- DATA ANALYSIS COORDINATOR
- GROUND ATTITUDE DETERMINATION SOFTWARE
- SYSTEM ENG/I&T SUPPORT
- SCIENCE/DATA ANALYSIS

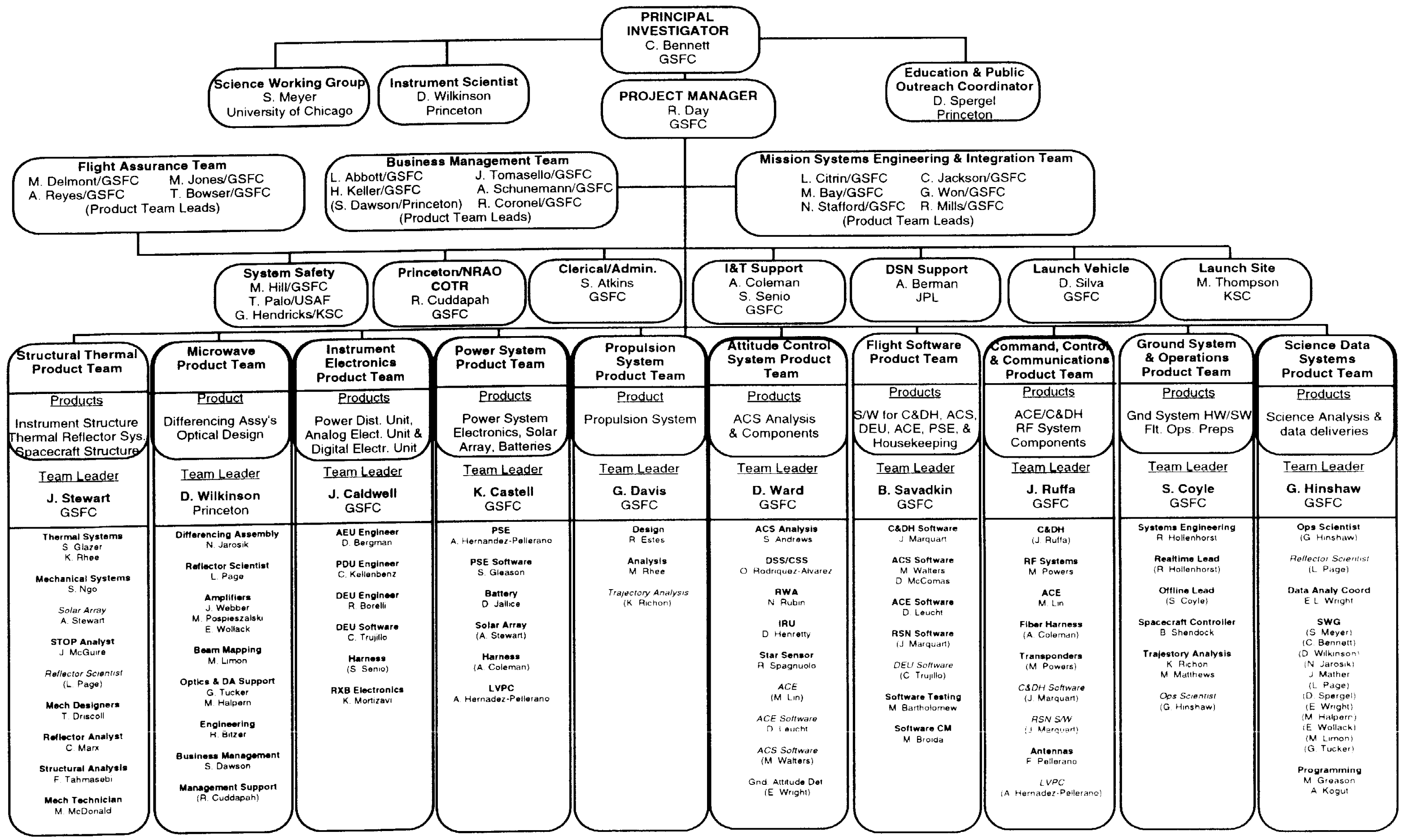
ACQUISITION STRATEGY

Project Overview

COMPONENT CATEGORY	MAKE OR BUY (RESPON.)	CONTRACT TYPE SUB TYPE	
THERMAL REFLECTOR SYSTEM	BUY (G)	FFP	PI
DIFFERENCING ASSEMBLIES	MAKE (P)	COST FFP	PI PR
MICROWAVE AMPLIFIERS	BUY (G)	INTER-AGENCY TRANSFER	N/ OI
INSTRUMENT, S/C STRUCTURES	MAKE (G)	N/A FFP	G! FA
ACS SENSORS & ACTUATORS	BUY (G)	FFP	LC KI
RF COMM. COMPONENTS	BUY (G)	FFP	TI
SOLAR CELLS	BUY (G)	FFP	TI

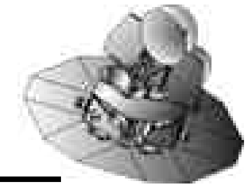


RMD 6/9/97



Note:
1) All positions are not full-time.
2) ( ) indicates additional team affiliations and responsibilities of an individual.
3) *Italics* indicate additional non-programmatic, subsystem engineering responsibilities of a product team leader.

ROLES & RESPONSIBILITIES HANDBOOK



- SUPPLEMENT TO ORGANIZATION CHART
- DISTRIBUTED TO TEAM AT PROJECT INITIATION AND UPDATED AS REQUIRED
- DEFINES RESPONSIBILITIES OF ~50 KEY INDIVIDUALS THAT FORM THE CORE OF THE MATRIX PROJECT TEAM
- BASIS FOR PERFORMANCE PLAN/EVALUATION INPUTS TO FUNCTIONAL LINE MANAGEMENT

EXAMPLE OF PRODUCT TEAM LEAD ROLE

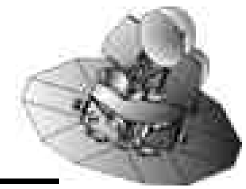
System-level responsibility and authority within allocated resources:

- Leadership of the product team and integral member of mission system engineering team
- Planning and control of technical, financial, schedule and human resources allocated to the product team
- Derivation, validation and verification of all system requirements relative to the product team
- Design and development of all deliverable products, including procured components, for which the product team is responsible
- Prevention of product, process and quality system non-conformities; identification and documentation of any problems relating to products, process and quality system; control of further processing until the non-conformance has been corrected; and implementation and verification of solutions with appropriate concurrence from the Flight Assurance Manager, Mission System Engineer and Project Manager
- Configuration management of all products and associated data packages

ROLE OF FUNCTIONAL LINE MANAGER AT GODDARD

- HOLDS A VESTED INTEREST IN THE SUCCESS OF MAP AND “FEELS” RESPONSIBILITY FOR THE ORGANIZATIONAL INPUT TO THE PROJECT
- ASSURES THE QUALITY OF THE ORGANIZATION’S INPUT TO THE PRODUCT
  - LINE OF APPEAL IF DISAGREES WITH TEAM DECISIONS
- MAINTAINS AND ENHANCES ORGANIZATION AND INDIVIDUAL CORE TECHNICAL CAPABILITIES
- EVALUATES PERFORMANCE OF TEAM MEMBERS BASED ON PROJECT MANAGER INPUT
- WORKS CLOSELY WITH PROJECT MANAGER TO ENSURE PROJECT NEEDS ARE MET

SAFETY & MISSION ASSURANCE OFFICE ROLE



- SUPPORT PROJECT MANAGER VIA:
  - DEFINITION & IMPLEMENTATION OF S&MA PROGRAM
  - INDEPENDENT ASSESSMENT THROUGH CONDUCT OF MAJOR SYSTEM REVIEWS
  - LAUNCH READINESS CERTIFICATION (“REDBOOK”)

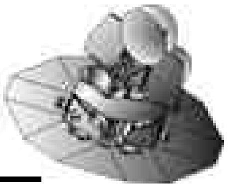
- PROVIDE INDEPENDENT ASSESSMENT AND CERTIFICATION OF SAFETY & MISSION ASSURANCE COMPLIANCE TO GODDARD CENTER DIRECTOR

- PROVIDE CERTIFICATION OF SAFETY COMPLIANCE TO NASA ASSOCIATE ADMINISTRATOR FOR SAFETY AND MISSION ASSURANCE

RELIABILITY POLICY

- MAP IS ALMOST ENTIRELY SINGLE-STRING
  - ACKNOWLEDGED BY ANNOUNCEMENT OF OPPORTUNITY
    - "AS A RESULT [OF PROGRAMMATIC DEMANDS], SYSTEMS ARE EXPECTED TO BE PRIMARILY NONREDUNDANT OR SINGLE-STRING. HOWEVER, REDUNDANCY IS ENCOURAGED WHERE APPROPRIATE AND WHERE RESOURCES ALLOW."
    - MAP RESOURCE CONSTRAINTS
    - MAXIMUM MASS TO ORBIT OF 708 kg.
    - MISSION COST CAP OF $70M (FY94)
- THEREFORE GREAT EMPHASIS IS PLACED ON:
  - ROBUSTNESS OF **DESIGN**
  - **MANUFACTURING** PROCESS CONTROL
  - **TESTING**, ANALYSIS AND SIMULATIONS
  - CLOSED LOOP ANOMALY REVIEW/DISPOSITION PROCESS

MAJOR PROJECT REVIEWS



- CONFIRMATION REVIEW (CR)
  - FAST TRACK MISSION SCHEDULE REQUIRES COMBINING ELEMENTS OF A CDR, MOR AND NAR
  - CO-CHAIRED BY SAFETY & MISSION ASSURANCE OFFICE AND EXTERNAL CO-CHAIR
- PRE-ENVIRONMENTAL REVIEW (PER)
  - EVALUATES SYSTEM ENVIRONMENTAL TEST PLANS
  - VERIFIES READINESS FOR SYSTEM TESTING
  - CHAIRED BY SAFETY & MISSION ASSURANCE OFFICE
- PRE-SHIP REVIEW (PSR)
  - VERIFIES READINESS OF ALL MISSION ELEMENTS FOR FLIGHT SEGMENT SHIPMENT TO LAUNCH SITE
  - FOCUS IS ON SYSTEM PERFORMANCE DURING TESTING
  - INCLUDES ELEMENTS OF A FLIGHT OPERATIONS REVIEW SUCH AS FLIGHT OPERATIONS PLANNING, FLIGHT/ GROUND COMPATIBILITY, END-TO-END TEST/ SIMULATION RESULTS
  - CHAIRED BY SAFETY & MISSION ASSURANCE OFFICE

MAJOR PROJECT REVIEWS
(CONTINUED)

- MISSION READINESS REVIEW (MRR) LAUNCH MINUS 1 MONTH
  - OBTAIN APPROVAL TO PROCEED TOWARD LAUNCH
  - SUCCESSIVE REVIEWS WITH GODDARD MANAGEMENT AND THE NASA ASSOCIATE ADMINISTRATOR FOR SPACE SCIENCE
- LAUNCH READINESS REVIEW (LRR) LAUNCH MINUS 3 DAYS
  - VERIFIES THE READINESS OF ALL MISSION ELEMENTS TO SUPPORT THE MISSION OBJECTIVES
  - OBTAIN CONCURRENCE FOR VEHICLE SECOND STAGE PROPELLANT LOADING
  - CHAIRED BY SAFETY & MISSION ASSURANCE OFFICE
- FLIGHT READINESS REVIEW (FRR) LAUNCH MINUS 1 DAY
  - FINAL AGREEMENT TO LAUNCH
  - CO-CHAIRED BY NASA MISSION DIRECTOR (MAP PROJECT MANAGER) AND NASA LAUNCH MANAGER (KSC EXPENDABLE LAUNCH VEHICLES DIRECTORATE)

- MISSION/OBSERVATORY LEVEL REVIEWS
  - ✔MISSION REQUIREMENTS - MAY 1996
  - ✔MISSION CONCEPT - JULY 1996
  - ✔SPACECRAFT DESIGN (PDR) - JANUARY 1997
  - ✔INSTRUMENT DESIGN (PDR) - MARCH 1997
  - ✔FLIGHT TRAJECTORY - MAY 1997
  - ✔MISSION RELIABILITY - MAY 1997
  - – FLIGHT OPERATIONS AND CONTINGENCY PLANNING
  - – PRE/POST-VIBROACOUSTICS TEST
  - – PRE/POST-THERMAL VACUUM TEST
  - – PRE/POST-TRANSPORT
  - – LAUNCH AND EARLY ORBIT
  - – TRAJECTORY AND MANEUVERS
  - – PRE/POST-PROPELLANT LOADING
  - – LAUNCH READINESS

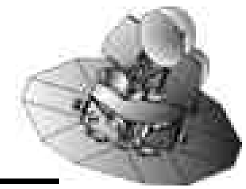
- INSTRUMENT/SPACECRAFT/GROUND SYSTEM
  - PRE-PROPULSION SYSTEM INTEGRATION (SPACECRAFT)
  - PRE-INTEGRATION (SPACECRAFT, INSTRUMENT)
  - PRE/POST-VIBRATION (INSTRUMENT)
  - PRE/POST-THERMAL VACUUM (INSTRUMENT)
  - ACCEPTANCE

- SUBSYSTEM/COMPONENT REVIEWS
  - PRELIMINARY DESIGN
  - CRITICAL DESIGN
  - PRE-FABRICATION
  - PRE-ENVIRONMENTAL TEST
  - ACCEPTANCE

LEVEL I SCHEDULE

INSERT MASTER SCHEDULES

MIDEX SPACECRAFT ADVANCED TECHNOLOGY



- EXPLORERS TECHNOLOGY INITIATIVE (MARCH 1995)
  - MAJOR REDUCTION IN NON-INSTRUMENT COST OF MISSIONS
  - MAKE SPACECRAFT SYSTEMS PERIPHERAL TO INSTRUMENT
    - BREAK THE INSTRUMENT/SPACECRAFT PARADIGM
  - FACILITATE A NEW GENERATION OF COMMERCIALLY AVAILABLE SPACECRAFT COMPONENTS
    - ENABLE CONTINUOUS TECHNOLOGY INFUSION
- MAP UTILIZES THIS REVOLUTIONARY NEW MODULAR DISTRIBUTED ARCHITECTURE
  - **MAP TEAM LEADS THE ETU AND FLIGHT DEVELOPMENT**
- CORE COMPONENTS COMMERCIALLY AVAILABLE
  - SPACE ACT AGREEMENT WITH LITTON AMECOM FOR TECHNOLOGY TRANSFER AND COLLABORATION

Systems Engineering

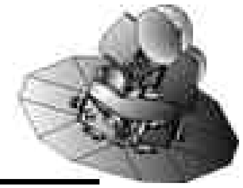
Systems Team:

- Mike Bay
- Liz Citrin
- Cliff Jackson
- Rick Mills
- Nancy Stafford
- Gary Won

AGENDA

- Requirements
- Environments
- Major Trades
- System Overview and Terminology
- Resources and Budgets
- Electrical Systems

MAP Requirements Overview



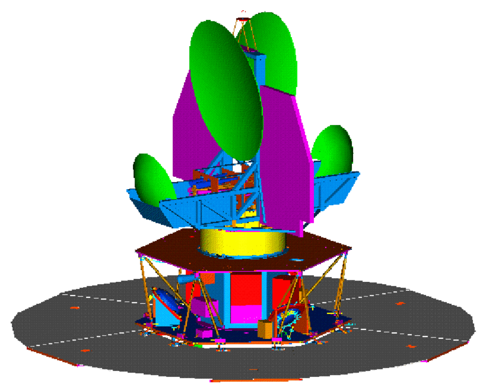
Systems Engineering

Science
- CMB map with:
- 20 uK sensitivity
- < 4.5 uK systematic errors
- 0.3º angular resolution
- Full-sky coverage
- Polarization sensitive

Mission
- 1-10 deg orbit about L2
- 27 month life (2 yrs. observing)
- Electrical System Specification
- Contamination: Class 100,000
- Radiation: 27krad total dose

Instrument
- Differential sensing using back-to-back Gregorian optics
- 5 frequency bands
  - 22GHz, 30GHz, 40Ghz, 60Ghz, 90GHz

Mechanical
- Shadow the instrument
- 7325 launch loads, 10 ft. fairing
- Sun-shade flatness
- Alignment and access



Attitude Control and Propulsion
- Compound spin observing strategy
  - 2.45-2.5º/sec @ 22.5º above spin plane
- Pointing knowledge of 1.8 arcmin RMS
- Spin axis precession 22.5º +/- .25º from sun vector
- Trajectory correction, orbit maintenance, momentum unloading

Thermal
- FPA HEMT's < 95K
- HEMT stability of 0.5mK p-p over spin period
- Electronics boxes 0-40C
- Inst. elect. stability of 10mK p-p over spin period
- Wet prop comp. - 10-50C

C&DH
- Real-time and stored commanding
- Real-time and stored telemetry
  - at least 30 hours on-board storage
- On-board timing resolution of 1ms
- Ground time correlation to 1s

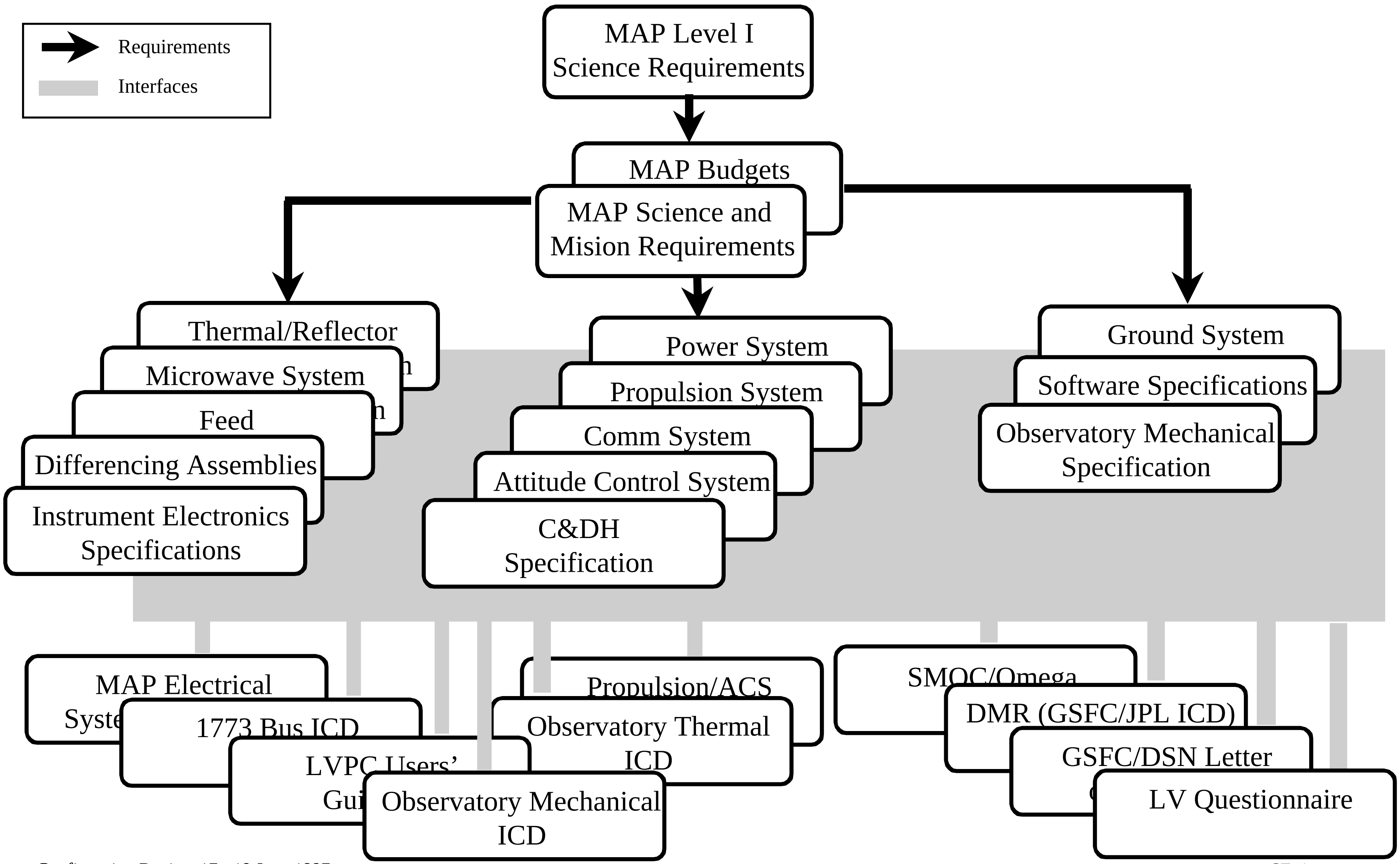
Comm
- CCSDS uplink @ 2kbps
- CCSDS downlink
  - minimize transmission
- 70m DSN prime, 34m bac
- 2-way tracking

Ground System
- Real-time and stored commanding
- Telemetry display
- Trending, level-0 processing
- Orbit, trajectory, and pass planning
- Data reduction and analysis (map making)
- Data archiving

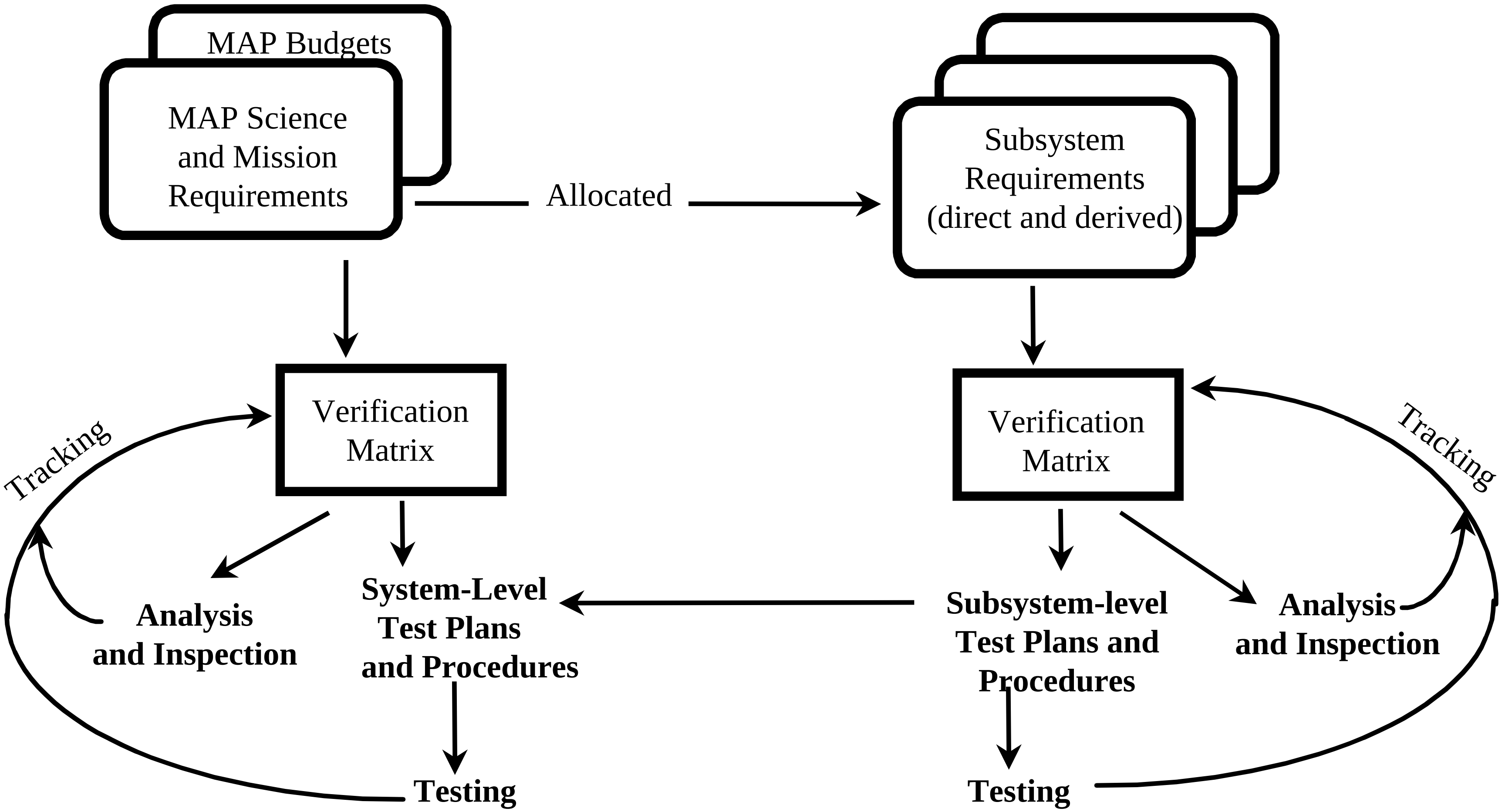
Power
- 400W EOL
- Energy storage to support initial sun acquisition and safemode entry
- Bus stability

Requirements Flow

Systems Engineering



REQUIREMENTS ALLOCATION AND VERIFICATION



Requirements and Verification Data Base

Requirement Table

Rqmt #	Requirement
...	
6.1.1	The sun shall be ...
6.1.2	Deleted
6.1.3	Sun acquisition ...
6.2	Implement a comp...
6.2.1	A 2.47-2.5 deg/sec ..
...	

Verification Traceability

Rqmt #	Test Title
...	
6.1.1	ACS12
...	
11.3.2	CDH17

Test Data Base

Test	Test Title	-Description -Pass/Fail Criteria -Procedure -GSE ...
CDH01	1773 Bus Communications	
CDH02	1773 Optical Margin	
CDH03	1773 Single Event Upset Simulatio	
...		

Allocation Table

Rqmt #	Subsystem
...	
6.2.1	ACS
6.2.2	ACS
...	

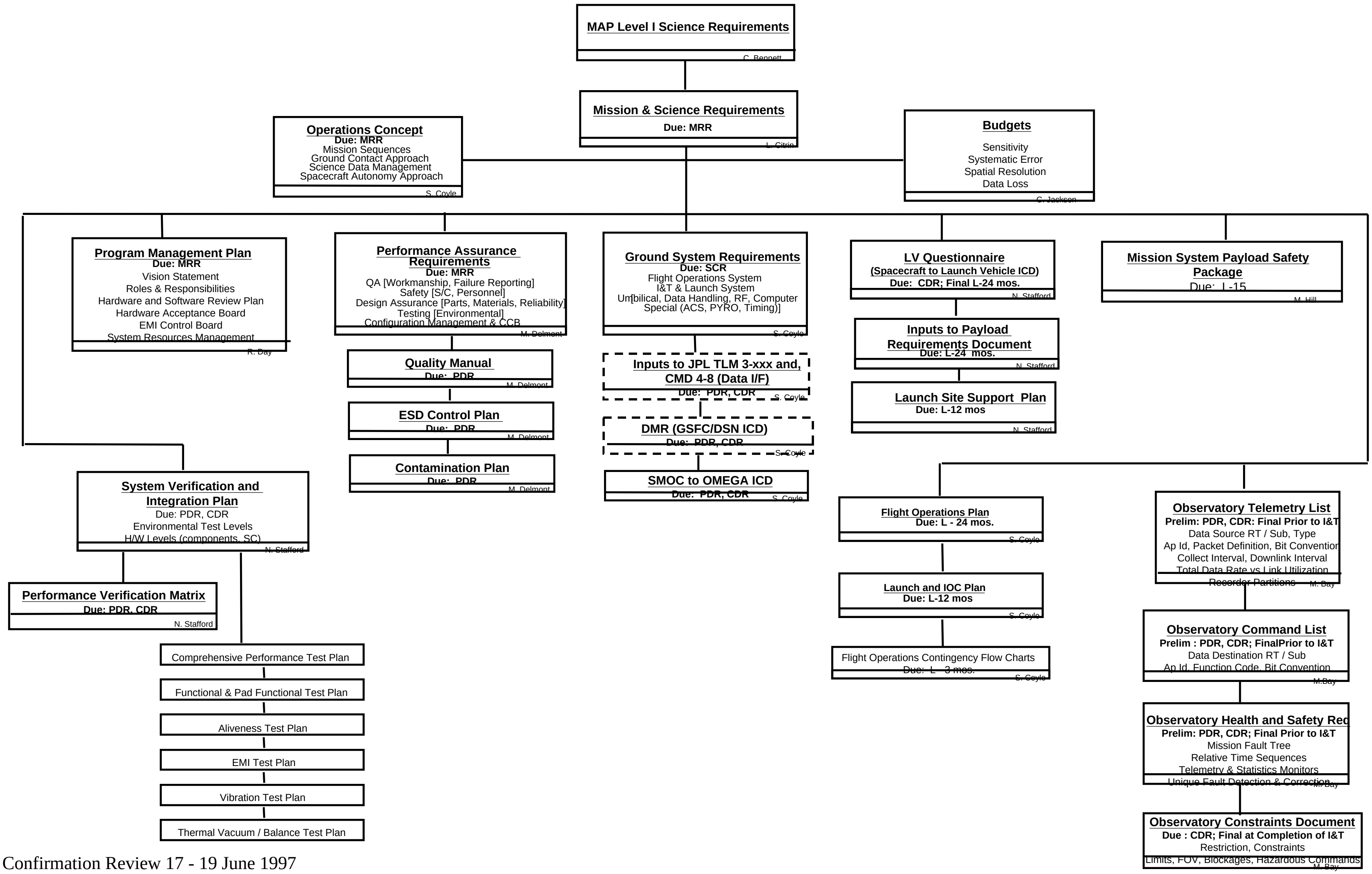
Tracking Table

Rqmt #	Test Results
...	
6.2.1	Pass
6.2.2	PFR #
...	

Systems Engineering

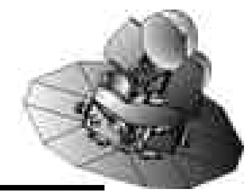
Map System Level Documentation Tree

May 5, 1997



Map System Level Documentation Tree

May 5, 1997



Systems Engineering

- **Mission & Science Requirements** — Due: MRR — L. Citrin
  - **Electrical Systems Specification** — Due: SCR — G. Won
    - Grounding Philosophy & Req (S/C & GSE)
    - Power Switchinh, Distribution Philosophy
    - Power Protection Philosophy & Req
    - Power System Voltage Range
    - Power Service EMI, Transients, Noise & Ripple
    - Shielding Philosophy & Req
    - Total Dose & SEU Requirements
    - **Wiring & Fusing Analysis** — Voltage Drops, wiring protection — K. Castell
    - **FMEA's** — G. Won
    - **Electrical Interface Analysis** — G. won
    - **Pig-tail/Star Coupler Spec** — A. Coleman
    - **Distribution and Grounding Diagrams** — G. Won
    - **Harness Drawing** — A. Coleman
  - **Observatory Mechanical Specification** — Due: PDR, CDR — Observatory Structure — J. Stewart
    - **Observatory Thermal ICD** — Due: PDR, CDR — J. Stewart
    - **Deployables System Specification** — Due: PDR, CDR — J. Stewart
    - **Mechanical/Thermal Resources** — Weight and CG, Temperature Predicts
    - **Observatory Mechanical ICD** — Due: PDR, CDR
  - **Command and Data Handling Specification** — Due: PDR, CDR — J. Ruffa
    - **C&DH Software Specs** — B. Savadkin
    - **C&DH System Resources:** Memory Utilization, CPU Utilization, Bus Utilization, Downlink Bandwidth Utilization, Recorder Utilization
    - **1773 Bus ICD** — Due: PDR, CDR — B Savadkin
  - **Communications System Specification** — Due : PDR — M. Powers
    - **Transponder Specification**
    - **Antenna Specification**
    - **DSN Letter of Agreement**
    - **Transponder to ESN ICD**
    - **RF Component Specs**
    - **RF System Resources:** RF Link Budgets
  - **Propulsion System Specification** — Due : PDR, CDR — G. Davis
    - **Propulsion Component Specs**
    - **Propulsion Resources:** Propellant Budget
    - **Propulsion ICD** — Due: PDR, CDR
  - **Power System Specification** — Due: PDR, CDR — K. Castell
    - **Pse Specification**
    - **Battery Specification**
    - **Solar Array Specification**
    - **PSE Software Specification** — B. Savadkin
    - **Power System Resources:** Solar Array Budget, Mission Mode Power
    - **LVPC Users' Guide/ICD** — Due: PDR
  - **Attitude Control System Specification** — Due : PDR, CDR — D. Ward
    - **ACS Component Specs**
    - **ACE Spec and ICD**
    - **ACS Software Requirements Document** — B. Savadkin
    - **ACS System Resource Budgets:** Knowledge, Jitter, Attitude Control
  - **PDU Specification** — Due: PDR, CDR — G. Kellenberg
  - **AEU Specification** — Due: PDR, CDR — D. Bergman
  - **DEU Specification** — Due: PDR, CDR — R. Bourelli
  - **Instrument S/W Specification** — C. Trujillo
  - **Thermal/Reflector System Specification** — Due : PDR — J. Stewart
  - **Microwave System Structure Specification** — Due: PDR, CDR — J. Stewart
  - **Feed Specification** — Due: PDR, CDR — L. Page
  - **Differencing Assemblies Specification** — Due: PDR, CDR — N. Jarosik

Specification and ICD Status

Systems Engineering

Document	Status	Comments
MAP Level I Science Requirements	Complete	
MAP Science and Mission Requirements	Complete	
Operations Concept Document	Complete	
Ground System Requirements	Complete	
Inputs to JPL TLM 3-xxx and CMD 4-8	In review	GSFC input complete. Sign-off needed in 6 months.
DMR (GSFC/DSN ICD)	Ready for DSN review	Need date: 6 months prior to compatibility testing.
DSN Letter of Agreement	In Progress	GSFC inputs complete 6/30. DSN review and sign-off by Aug. 15, prior to Transponder contract award.
SMOC to OMEGA ICD	Complete	
Launch Vehicle Questionnaire	Complete	
Electrical System Specification	Complete	
Electrical Interface Analysis	On-going	In-house and some procured components reviewed. Remaining Specs reviewed for all components but detail analysis TBD for transponder, wheels, gyro, tracker.

Specification and ICD Status (2)

. Systems Engineering

Document	Status	Comments
Observatory Mechanical Specification	Complete	
Observatory Mechanical ICD	Complete	Interface definition envelopes (volume, footprint, mass, finish) agreed to and distributed in subsystem/component specs. Final box/component drawings to be complete by 7/15.
Observatory Deployables Specification	Complete	
Observatory Thermal ICD	Complete	
Command & Data Handling Specification	Complete	
1773 Bus ICD	In review	Complete except for AST interface
Communications System Specification	Complete	
Propulsion System Specification	Complete	
Propulsion Component Specs		Thruster, fill and drain valve specs complete. Pressure transducer, filter and iso-valve specs to be complete, RFP's issued by 7/30.
Propulsion ICD	Complete	
AEU Specification	Complete	
Digital Electronics Unit Specification	Complete	
Power Distribution Unit Specification	Complete	
Feed Specification	Complete	
Differencing Assembly Specification	Complete	

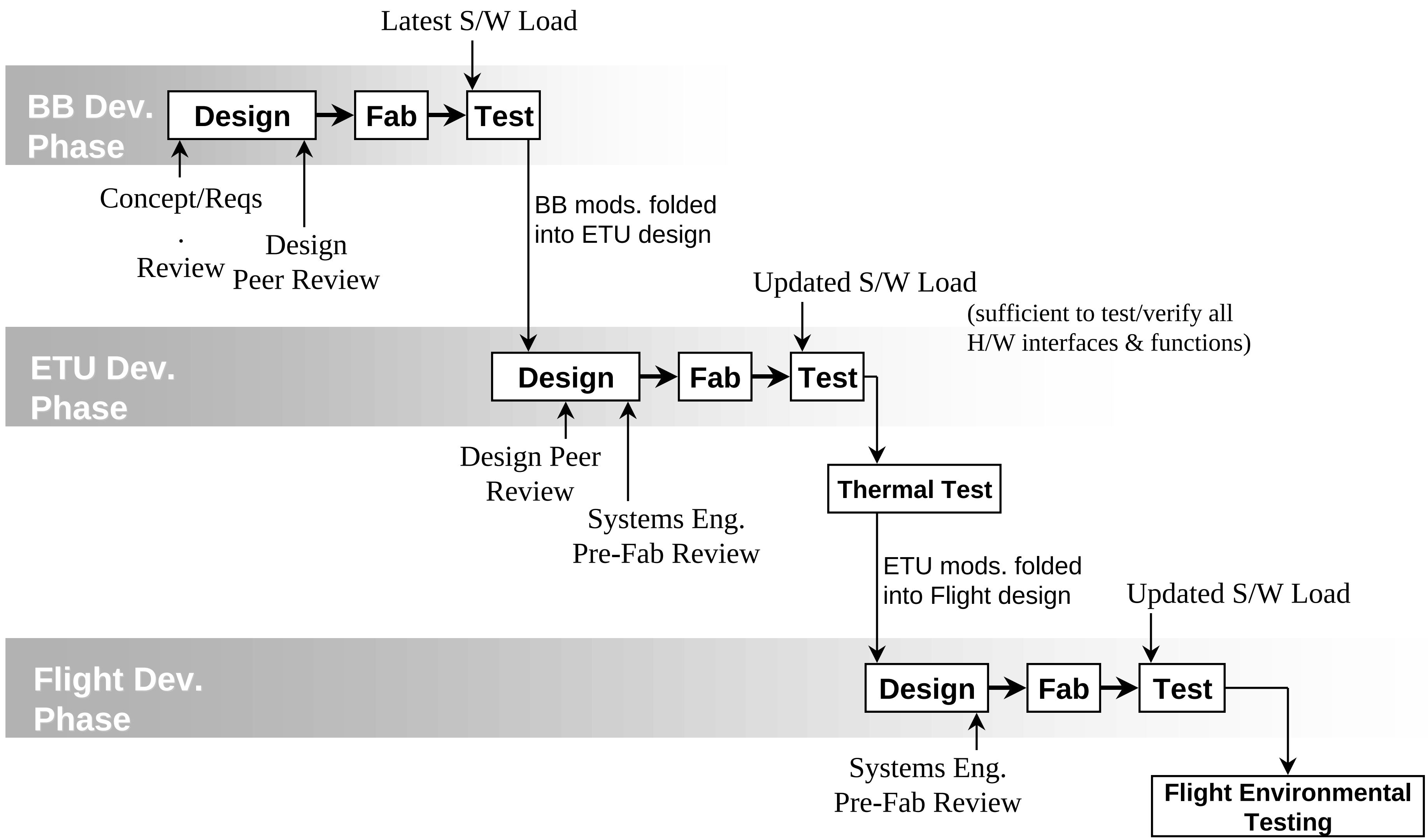
Specification and ICD (3)

Systems Engineering

Document	Status	Comments
Microwave System Structure Specification	In progress	DA positioning complete except for final component dimensions of K & Ka detectors, due now. Supporting rib structure design complete 7/15.
Thermal Reflector System Specification	Complete	
Power Subsystem Specification	Complete	
LVPC Users' Guide/ICD	Complete	
Attitude Control Subsystem Specification	Complete	
ACS Component Specs	Complete	
ACE Specification and ICD	In progress	Incorporating recently awarded component interface details. Complete 7/30.
PSE Software Specification	Complete	
ACS Software Requirements Document	In review	All Build 1 (ACE and ACS) requirements finalized. Document sign-off 6/30.
C&DH Software Specifications	Build 1 specs complete or in-review.	C&DH Spec for each software component. Specs for each component are completed prior to integration of component into the Build.
Instrument Software Specification	Complete	

Subsystem Development Approach

Systems Engineering



Subsystem Reviews

- Concept/Requirements Review
  – Early in design phase; internal with systems participation
  – Requirements defined and understood; viable design and operations concept
- Design Peer Review(s)
  – Prior to committing to fabrication (BB, ETU, Flight)
  – Requirements, design (schematic level), operations & verification approach
  – Circuit functionality, interface compatibility, FMEA’s, robustness reviewed
  – External as well as internal peer participation
- Pre-Fab Review(s)
  – Prior to ETU, Flight fab
  – CCA layout review, with systems & other experts
  – Review isolation, grounding, good practice guidelines

Peer Reviews

- ACS
  - Concept Review 7/96; PDR 1/97, CDR 5/97
  - S/W PDR 1/97
  - ACE, EVD, I/O Card detailed design reviews
  - GSE Review
- Power
  - SA, Output, Battery, Control Module, LVPC Schematic/Detailed design reviews
  - Layout/Packaging Reivew
  - GSE Review
  - Power System Operations Review
- Propulsion
  - Peer Review #1
  - Peer Review #2
- C&DH
  - HSK RSN, XRSN, M-V detailed design reviews
  - GSE Review
  - ACE, EVD, I/O Card detailed design reviews
  - GSE Review
- Comm
  - Subsystem Peer Review 12/96
- Instrument
  - Peer Review
- Ground System and Operations
  - Requirements Review
  - Design Reivew
  - Trajectory Design Review
- Mechanical/Thermal

Peer Reviews(2)

- Flight Software
  - **Generic RSN Requirements & Design Review 4/97**
  - **Command Ingest Delta Design Review 2/97**
  - **Checksum Requirements Review 3/97**
  - **Health & Safety Delta Review 2/97**
  - **Operating System Requirements Review 1/97**
  - **Memory Scrub Requirements Review 12/96**
  - **Memory Scrub Design Review 1/97**
  - **Software Manager Req. Review 8/96**
  - **Time Code Req. Review 7/96**
  - **Time Code Design & Code Review 8/96**
  - **Telemetry Output Req. Review 10/96**
  - **Telemetry Output Design Review 1/97**
  - **1773 Bus Controller Req. Review 1/95**
  - **1773 Bus Controller Design Review 9/96**
  - **PSE S/W Req. Review 8/96**
  - **PSE S/W Design & Code Review 10/96**
  - **RSN Bootstrap Loader Design Review 3/97**
  - **Transponder RSN S/W Requirements Review 4/96**
  - **Transponder RSN S/W Design & Code Review 4/96**
  - **ACS FSW PDR 4/97**
  - Flight Software CDR for 9/97
  - Remaining S/W component Rqmts and Design Reviews
  - Code Walkthroughs
- Mechanical
  - **GSE Review 11/96**
  - **Mechanical Peer Review 2/97**
  - **Deployables Peer Review #1 2/97**
  - **Deployables Peer Review #2 6/97**
  - **TRS CDR 6/97**
  - Mechanical Peer Review #2 8/97
  - TRS PSR
- Comm
  - **Comm Subsystem Peer Review 11/96**
  - **GSE Review 11/96**
  - Med. Gain Antenna ETU Design Rev. 8/97
  - Med. Gain Antenna ETU Pre-fab Rev. 9/97
  - Transponder Design Review 12/97; PSR 8/98
  - Med Gain Antenna Flight Pre-fab Rev. 1/98
- Thermal
  - **Thermal Peer Review #1 1/97**
  - **Thermal Peer Review #2 6/97**
  - Thermal Peer Review #3 10/97
- Propulsion
  - **Peer Review #1 10/96**
  - **GSE Review 11/96**
  - **Peer Review #2 5/97**
  - Peer Review #3 (pre-fab) 9/97

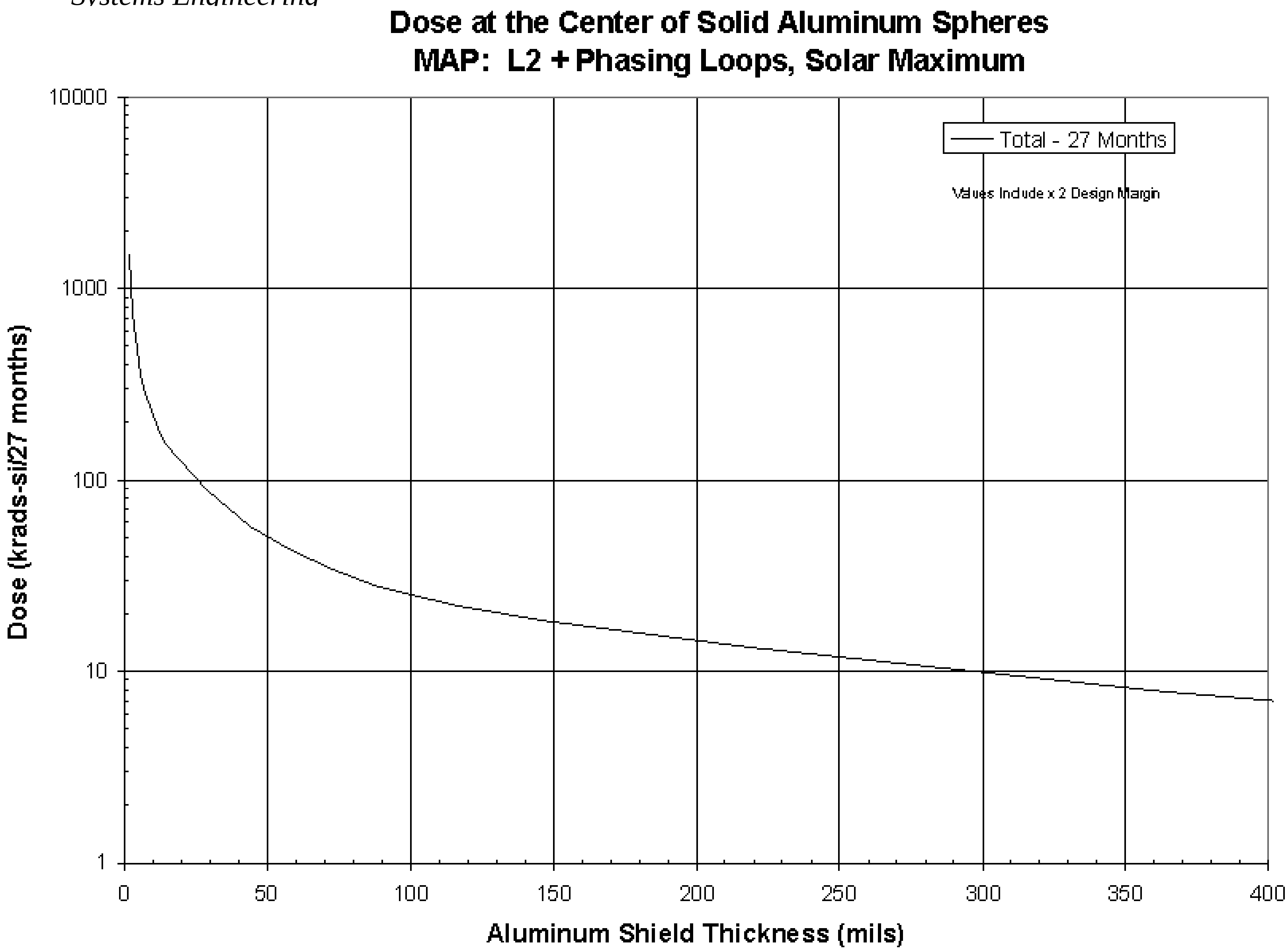
Environments

MAP Radiation Environment

- Total dose prediction: 27krad-si
  - Assuming 27 month mission; 100 mil aluminum shielding; design margin of 2
  - Ray trace of lightweight box shows 6-10 krad-si interior environment
  - Ray trace of selected observatory points
- SEE requirements
  - Parts immune to latchup; parts with LETth < 35 MEV*cm^2/mg shall be shown to not degrade mission performance
- Status:
  - All parts lists have been reviewed for total dose and SEE susceptibility
  - TID radiation testing in progress; no issues anticipated
  - SEE impact analysis in process for susceptible parts; no issues anticipated

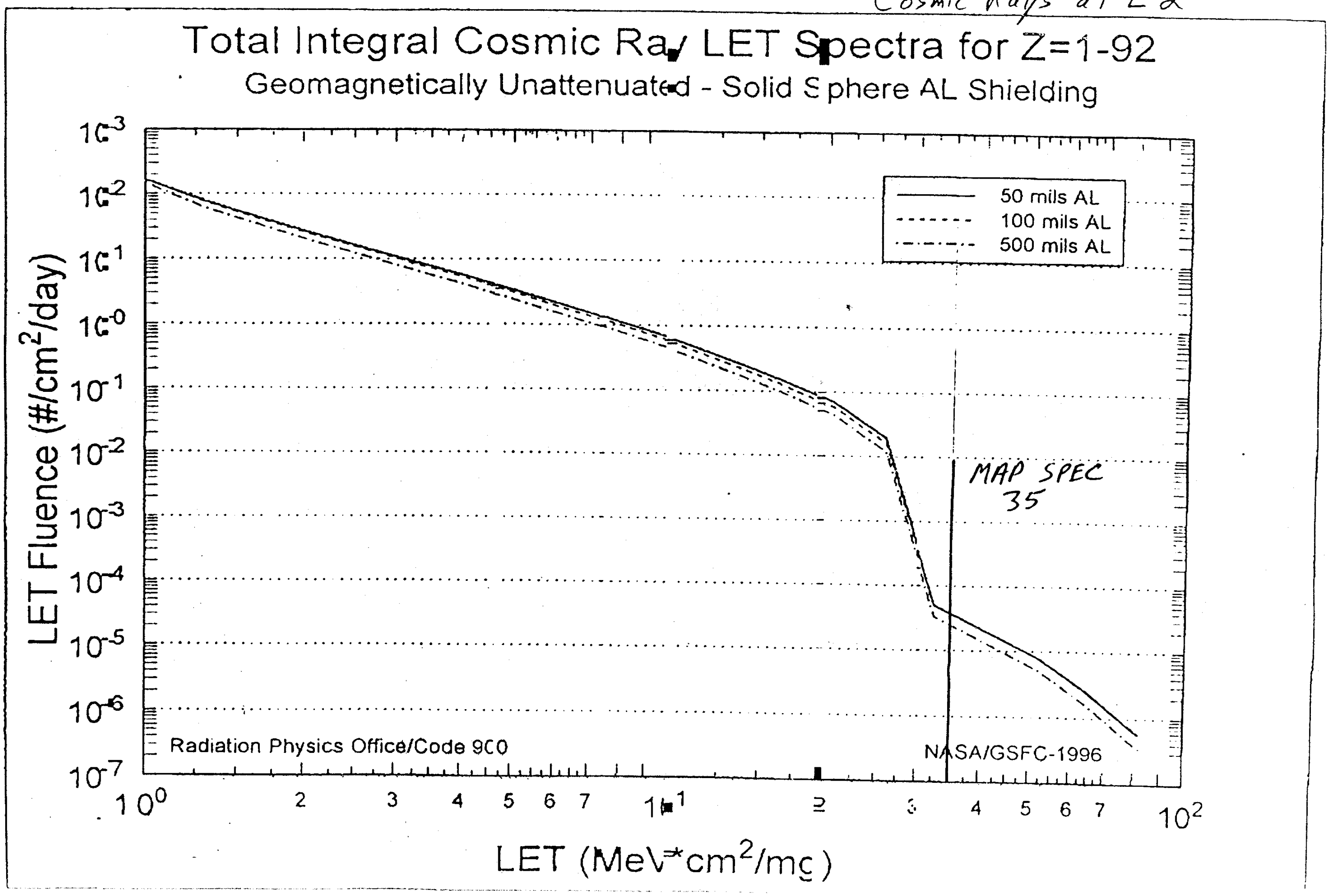
MAP Total Dose Curve

Systems Engineering



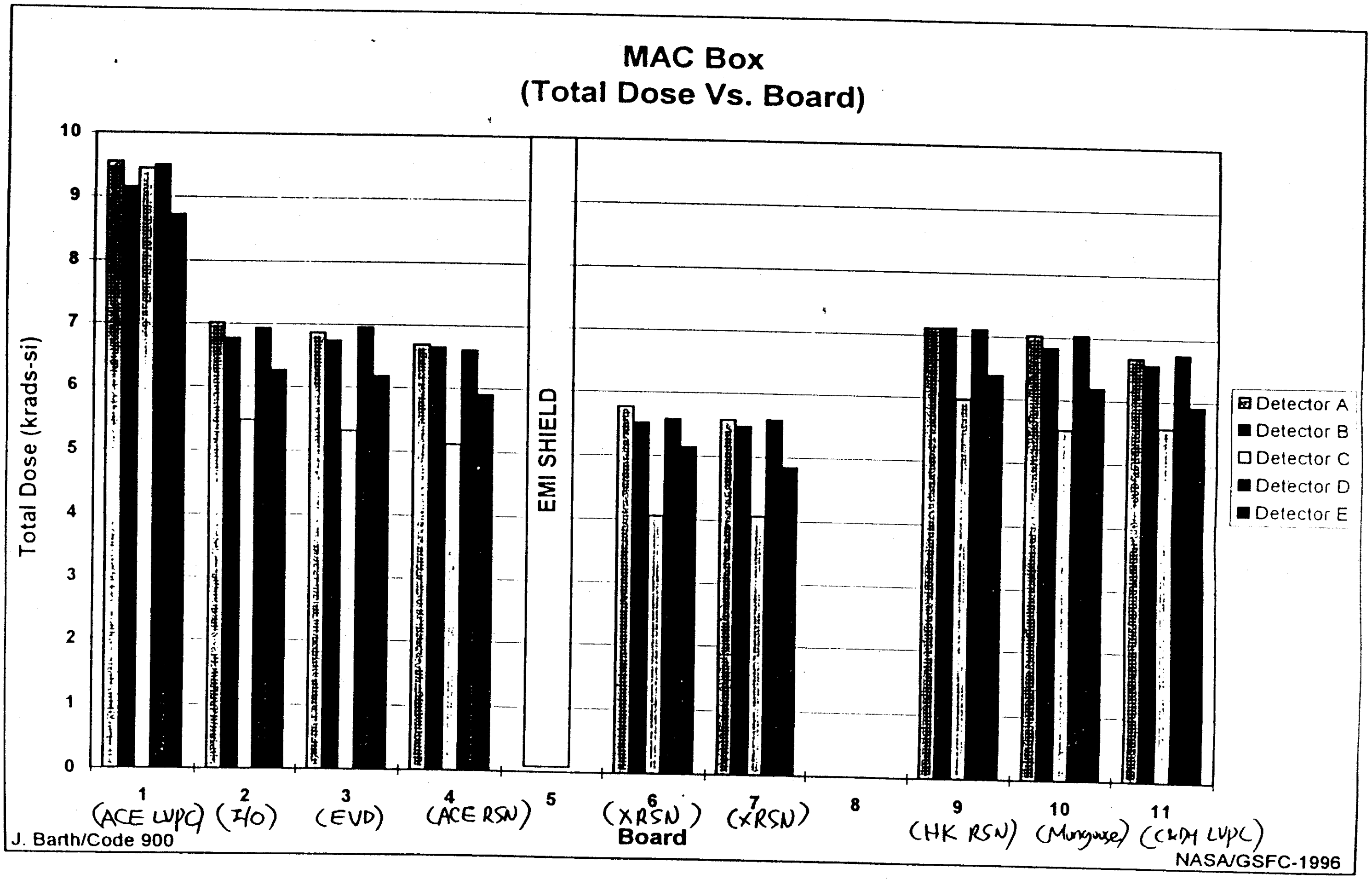
LET Spectra

Cosmic Rays at L2

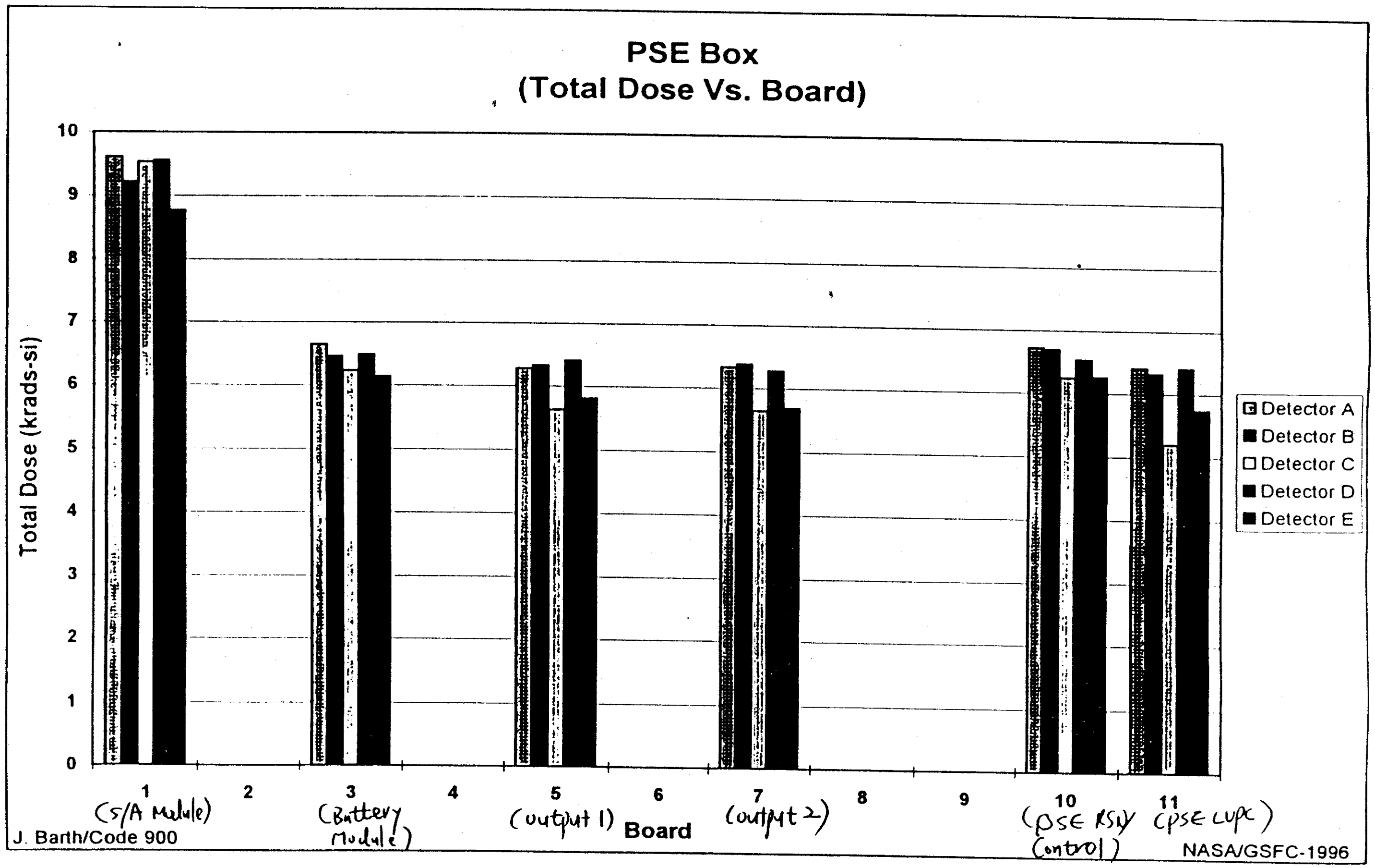


MAC Box Analysis

Systems Engineering



PSE Box Analysis



S/C Charging

- Environment benign at L2
  – Vulnerable during geosynchronous-like region of phasing loops (6-10 earth radii, ~3 hours/7day loop)
- Mitigation
  – External surfaces conductive ($<10^9$ ohms/square) and grounded
- Issues being worked:
  – Conductivity of SiOx coating on reflector not yet known
    - Building test samples for measurement; will complete by TRS CDR in August
  – Handling difficulty of Fep/Ag/ITO on sun-side webbing between solar panels
    - Obtaining test samples for analysis
    - Investigating other materials (bakelite)
    - Investigating necessity of conductive requirement on the sun-side
    - Analysis complete prior to flight blanket fabrication (1998)

Contamination

- MAP relatively insensitive to particulate contamination
  - Visibly clean per JSC-SN-C00005, Rev C
  - Class 100,000 facilities sufficient for I&T activities
  - Particulant contamination levels maintained by inspection and cleaning , facility monitoring
- Condensable contamination sources are propellant, MLI, and truss structure
  - ~50,000 Å of condensables on reflector and radiator surfaces acceptable
  - Analysis results show < 20,000 Å deposition on surfaces, stacked worst case; much less on reflector surfaces
- Humidity poses potential problem for unpassivated HEMT amps (W band only)
  - I&T activities will be performed in a 40-60% relative humidity environment
  - HEMT's will be purged during periods of inactivity with dry gas

MAP Thruster Summary

NH_3 Deposition on Critical Surfaces (Å/kg fuel)

LOCATION	#3 Thruster 30°	#3 Thruster 45°	#4 Thruster 30°	#4 Thruster 45°	#5 Thruster	#6 Thruster
Primary Mirror						
-Y side(#25)	104.4	7.5	104.4	7.5	1.1	0
+Y side(#26)	104.4	7.5	104.4	7.5	0	1.1
Secondary Mirror						
-Y side(#27)	24.2	2.7	24.2	2.7	0.1	0
+Y side(#28)	24.2	2.7	24.2	2.7	0	0.1
Radiator						
+X side(#4 facing -Y)	0	0	0	0	0	0
+X side(#10 facing +Y)	0	0	0	0	0	0
-X side(#16 facing -Y)	0	0	0	0	562.7	0
-X side(#22 facing +Y)	0	0	0	0	0	562.7

[1]. #3 and #4 are cold-side thrusters; considered both cant angles (30° and 45°).
[2]. #5 and #6 are radial-side thrusters.
[3]. Assumed all impinged plume products stick to surfaces.
[4]. Considered H_2O and NH_3 as two major constituents.

M·P Plume Summary 06/97 Philip Chen

MAP Thruster Summary (continued)

MAP Thruster Summary (continued)

H_2O Deposition on Critical Surfaces (Å/kg fuel)

LOCATION	#3 Thruster 30°	#3 Thruster 45°	#4 Thruster 30°	#4 Thruster 45°	#5 Thruster	#6 Thruster
Primary Mirror						
-Y side(#25)	11.1	0.8	11.1	0.8	0.1	0
+Y side(#26)	11.1	0.8	11.1	0.8	0	0.1
Secondary Mirror						
-Y side(#27)	2.6	0.3	2.6	0.3	0	0
+Y side(#28)	2.6	0.3	2.6	0.3	0	0
Radiator						
+X side(#4 facing -Y)	0	0	0	0	0	0
+X side(#10 facing +Y)	0	0	0	0	0	0
-X side(#16 facing -Y)	0	0	0	0	59.5	0
-X side(#22 facing +Y)	0	0	0	0	0	59.5

[1]. #3 and #4 are cold-side thrusters; considered both cant angles (30° and 45°).
[2]. #5 and #6 are radial-side thrusters.
[3]. Assumed all impinged plume products stick to surfaces.
[4]. Considered H_2O and NH_3 as two major constituents.

MAP Plume Summary 06/97 Philip Chen

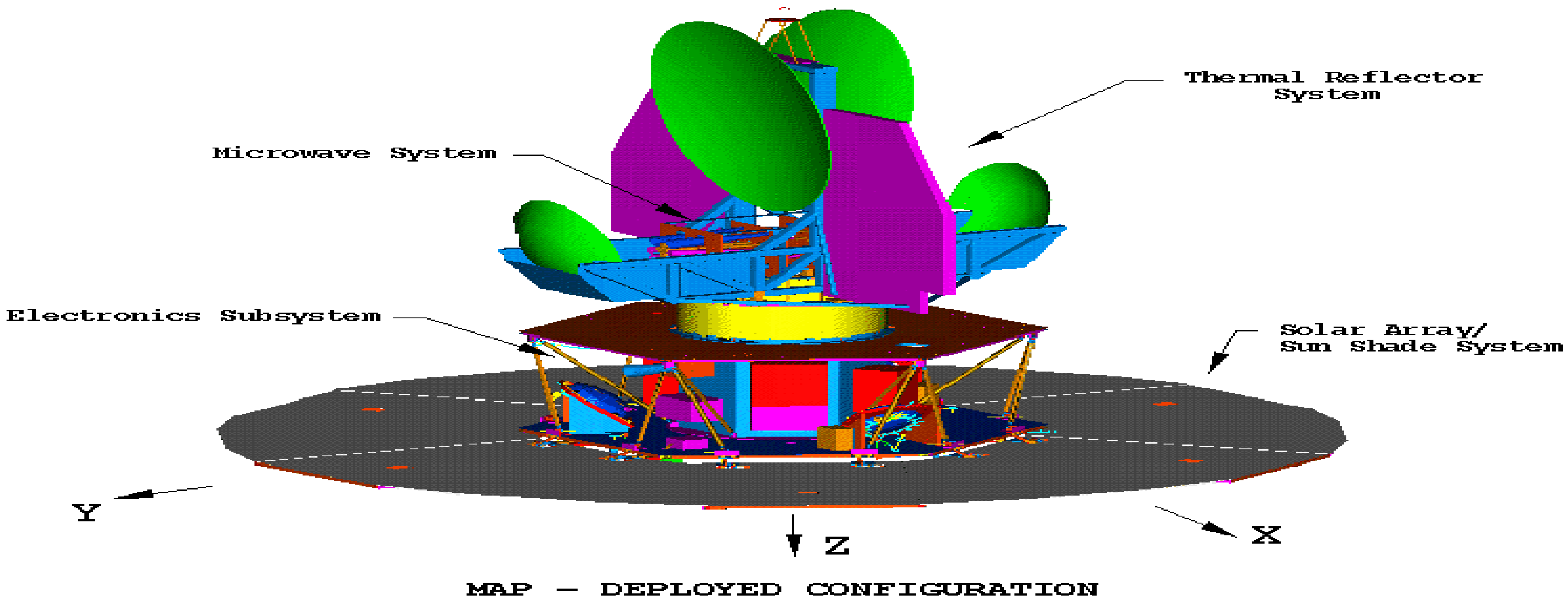
Orbital Debris

- Potential debris sources limited to:
  - Delta 3rd stage and yo-yo cable
  - MAP solar array deployment cable
- Preliminary analysis shows these items to be within acceptable guidelines (per NSS 1740.1H)
  - Due to highly elliptical orbits of the items, time spent below <2000 km is small
- Post-mission disposal policy guidelines not applicable to MAP spacecraft at L2

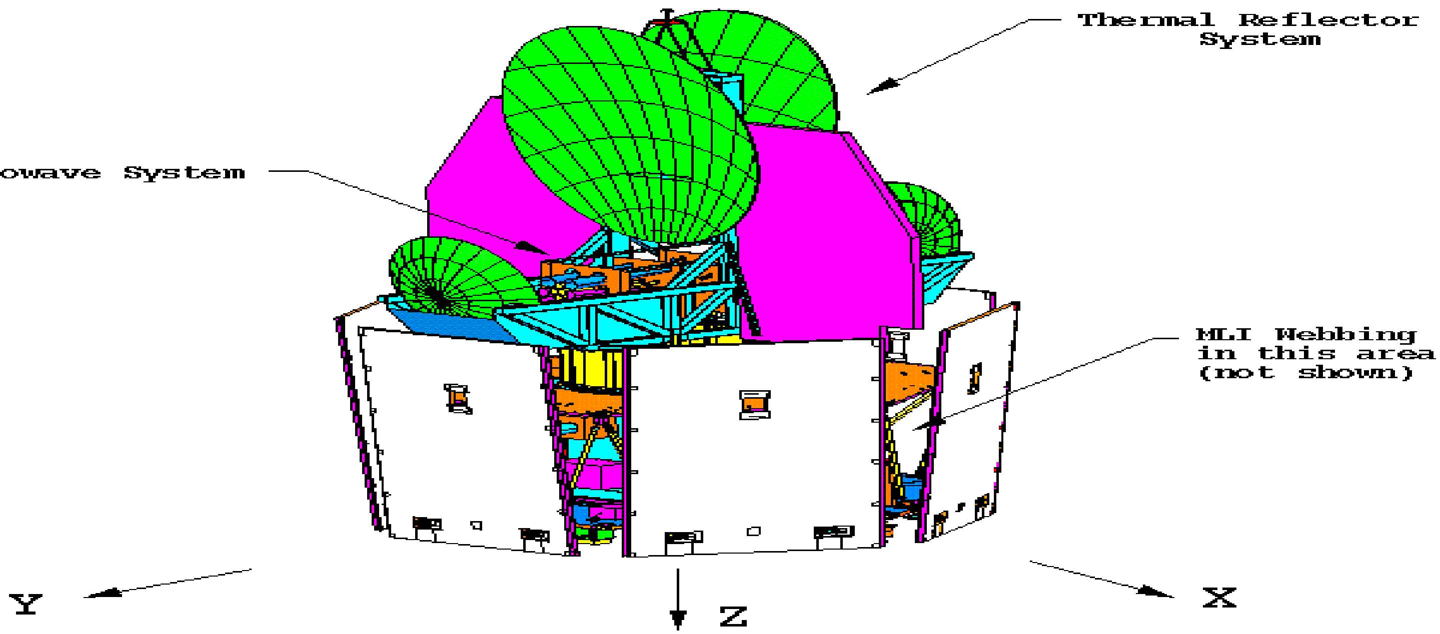
MAJOR TRADES

- Increase momentum storage of reaction wheels
  – More robust acquisition and observing mode
- Vehicle yo-yo despin instead of spacecraft yo-yo
  – More cost efficient
- Change spacecraft maneuver strategy to achieve required predictability
  – Steer observatory rather than thrust vector
- Shaped vs. pure conic optics
  – Improved spatial resolution

MAP
Deployed Configuration

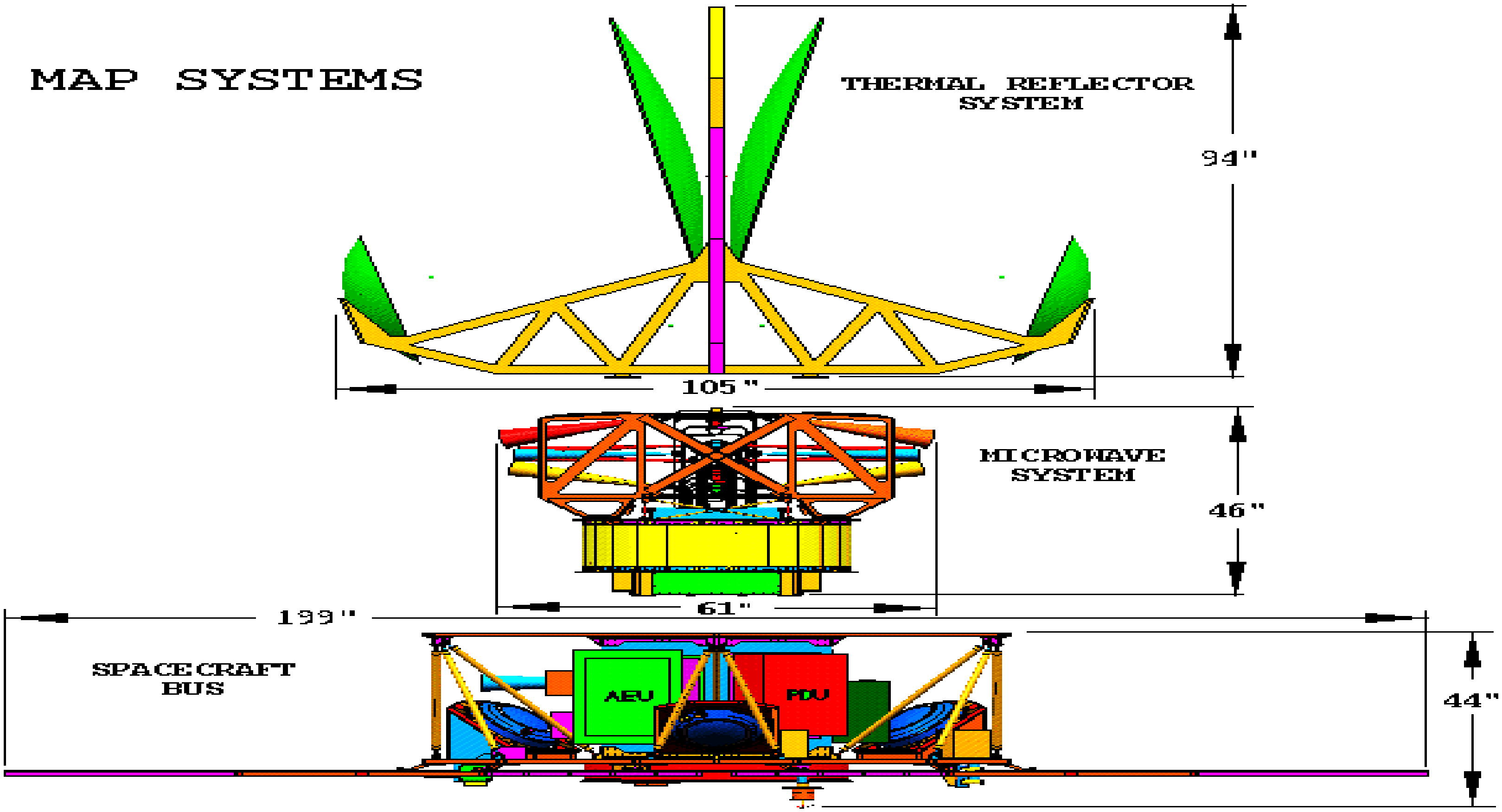


MAP
Stowed Configuration

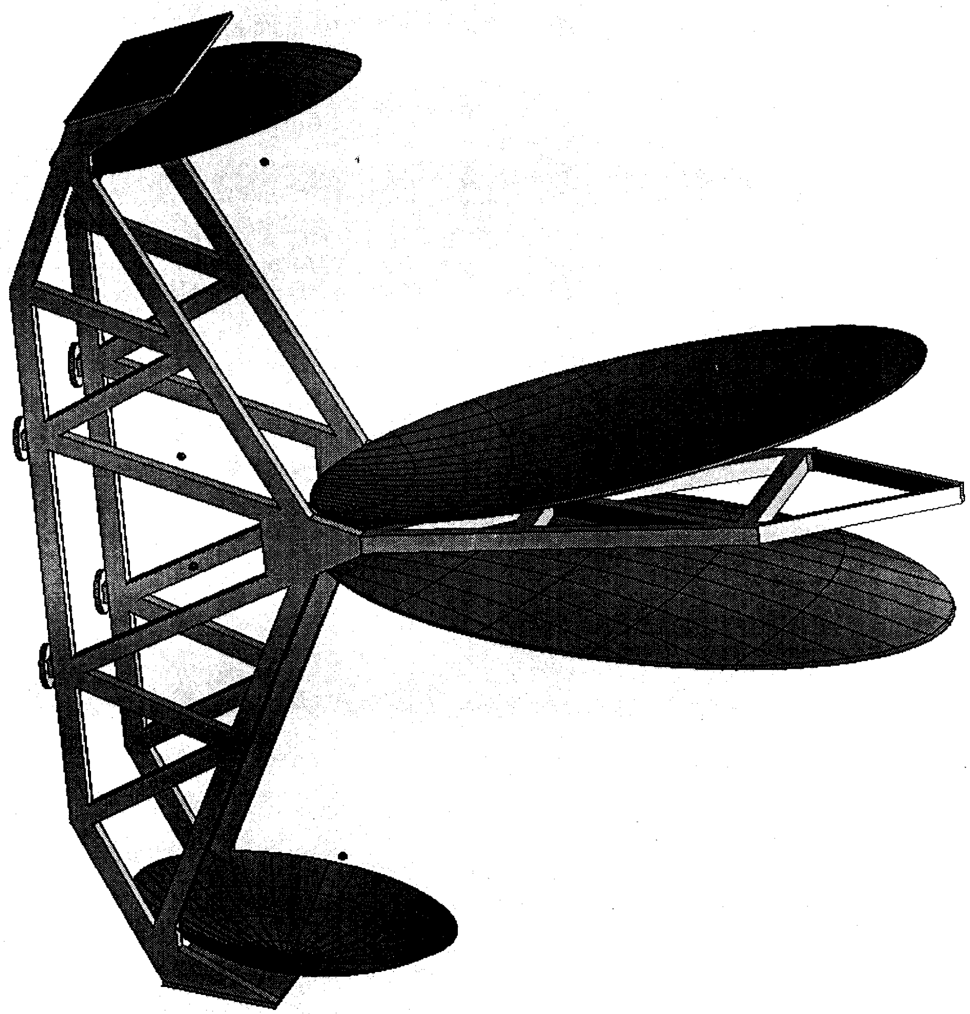


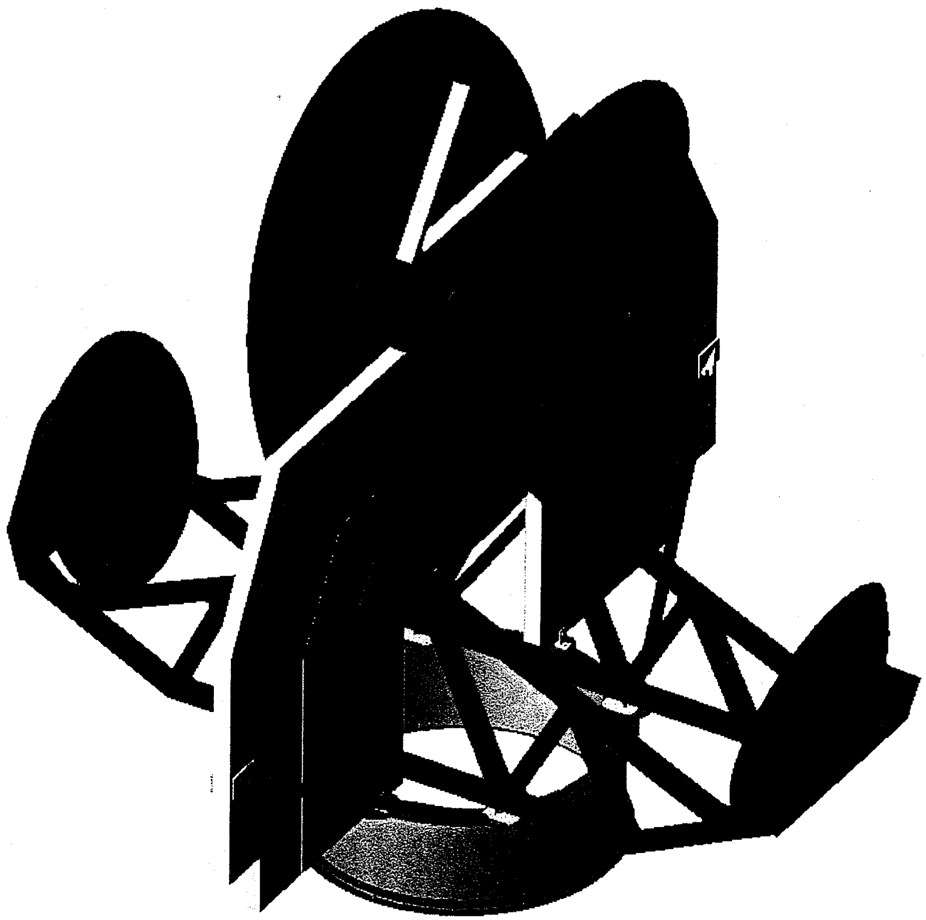
MAP - STOWED CONFIGURATION

MAP SYSTEMS

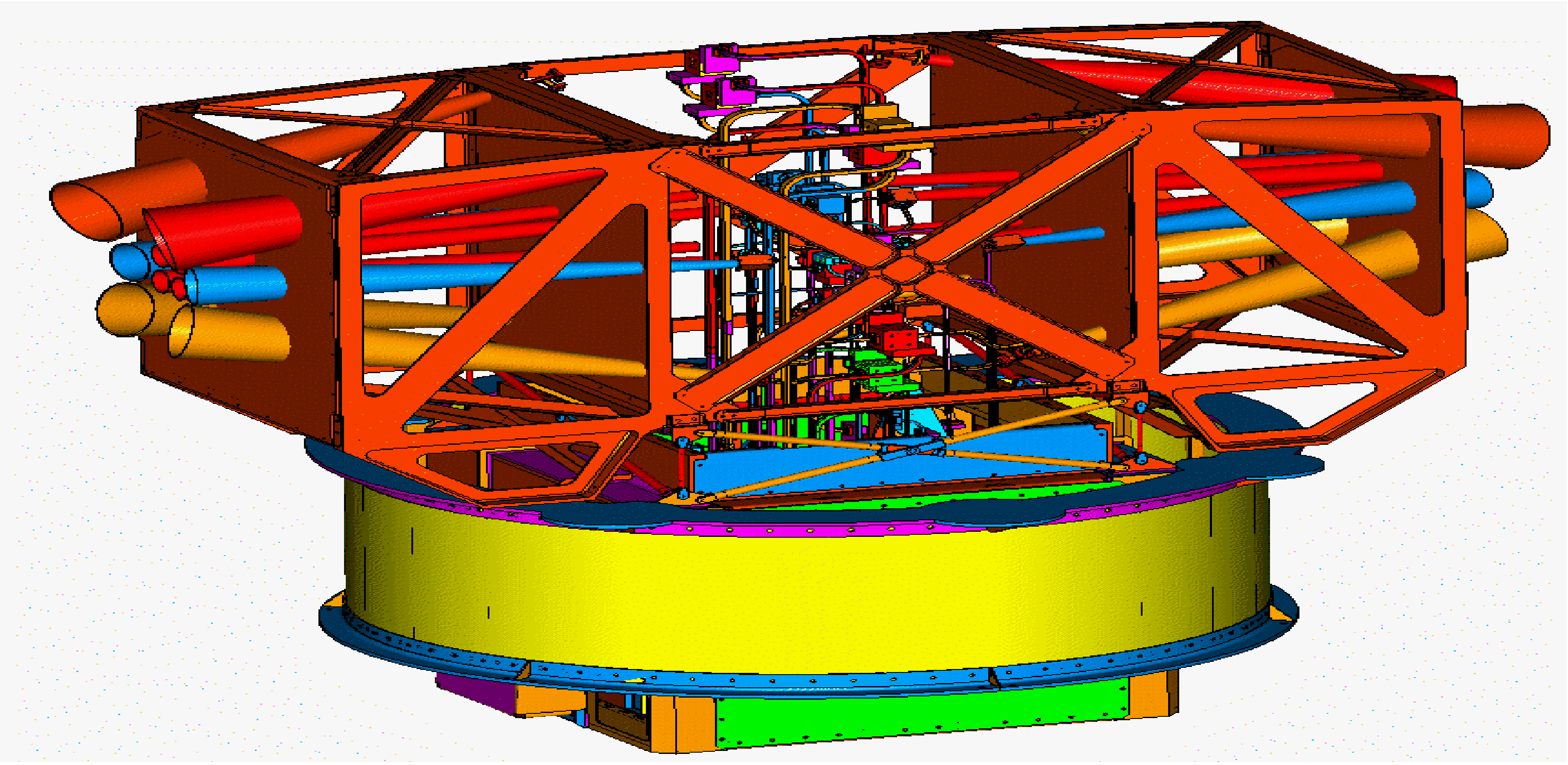

THERMAL REFLECTOR SYSTEM
94"
105 "
MICROWAVE SYSTEM
46"
61"
199"
SPACECRAFT BUS
AEU
PDU
44"

MAP Thermal Reflector System (TRS)

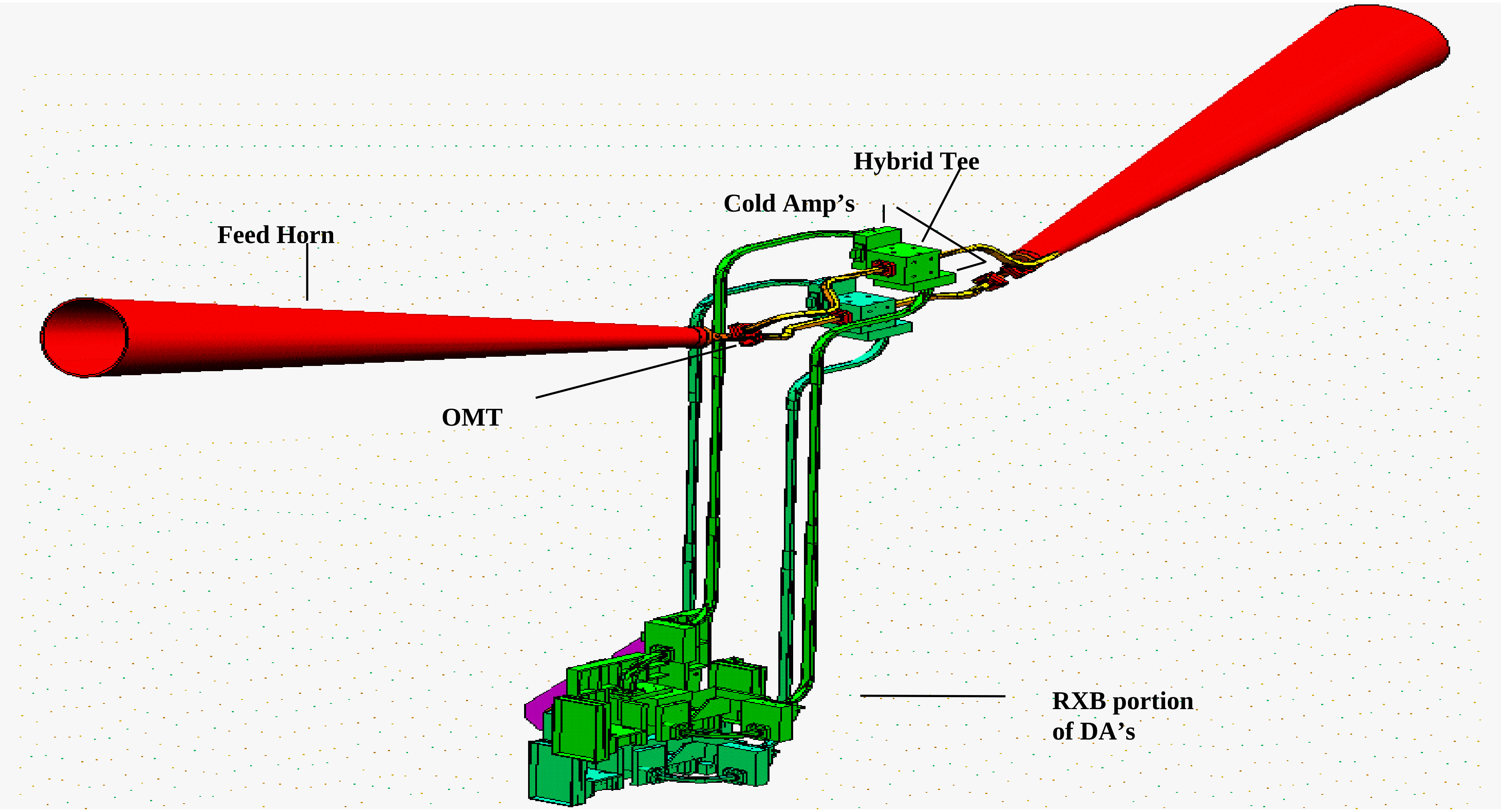




MAP Microwave System

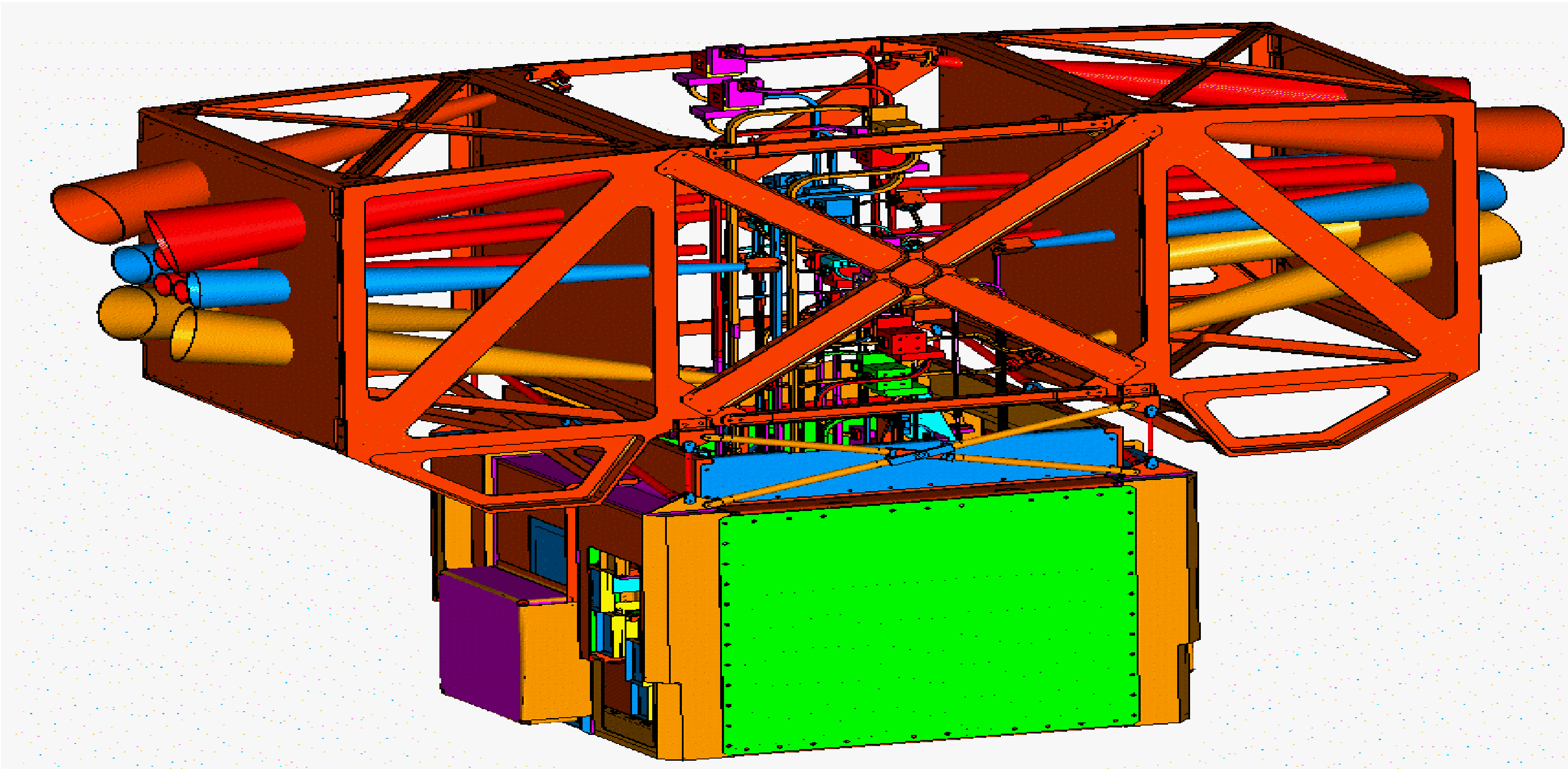


MAP
Differencing Assembly

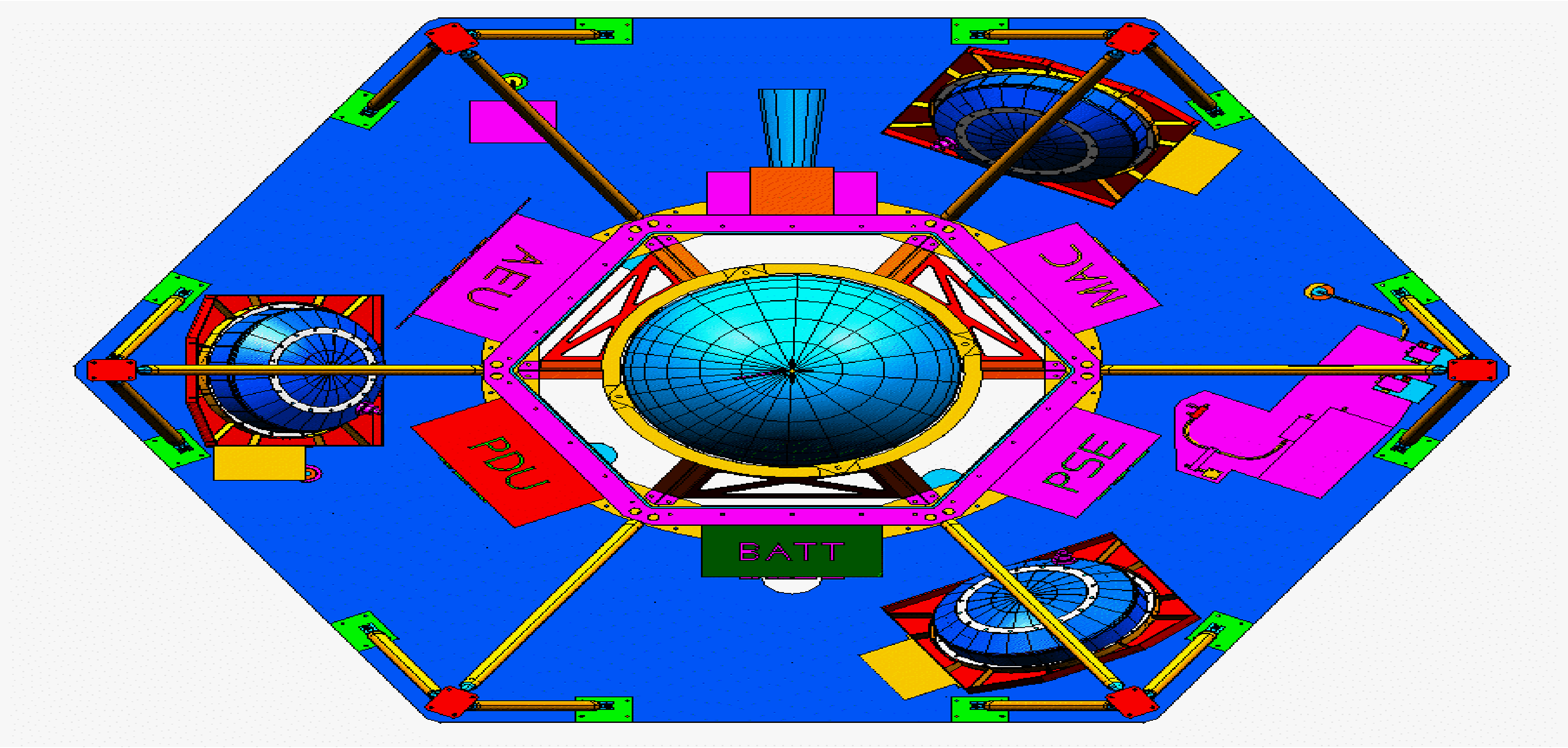


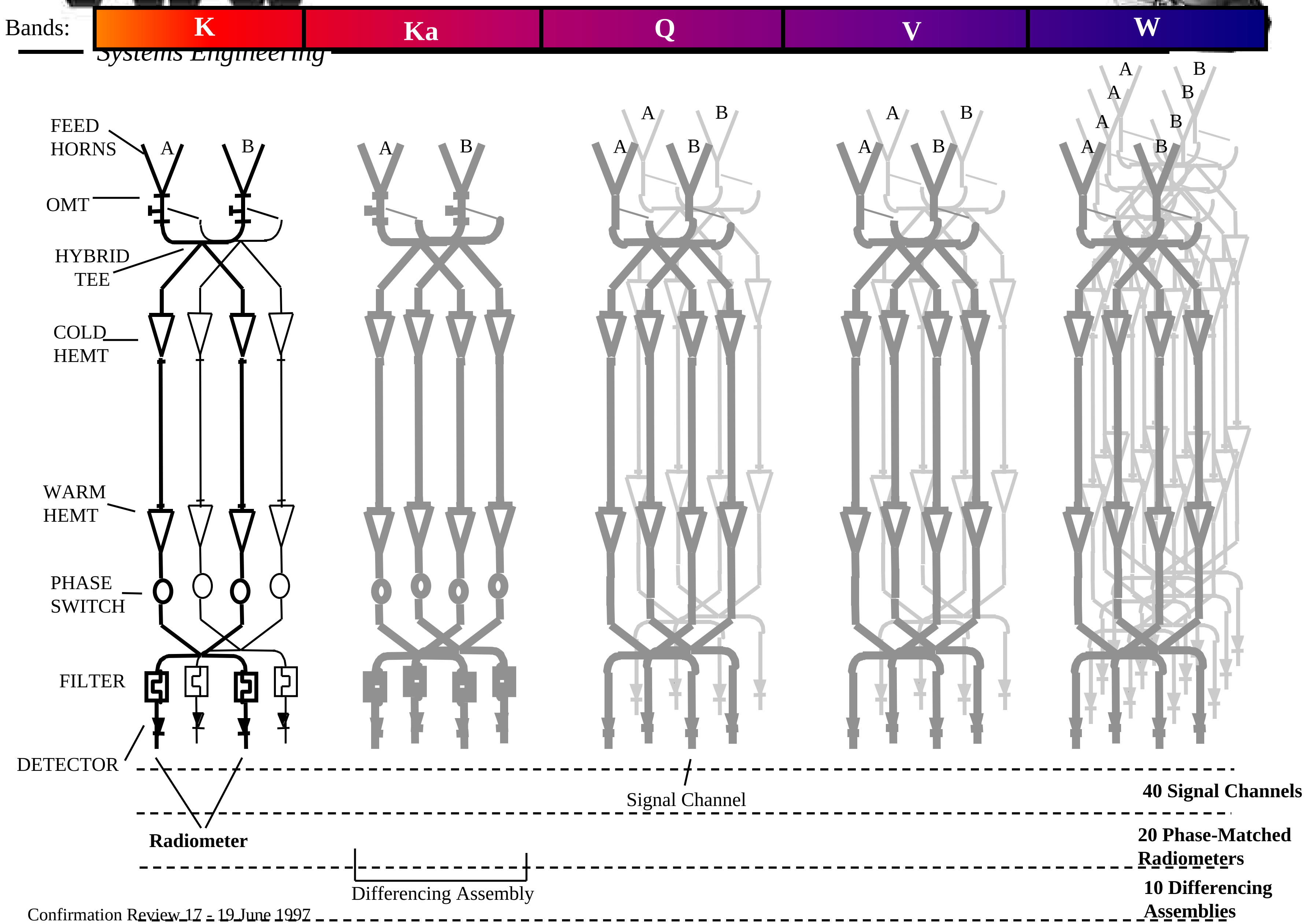
MAP Microwave System

Systems Engineering

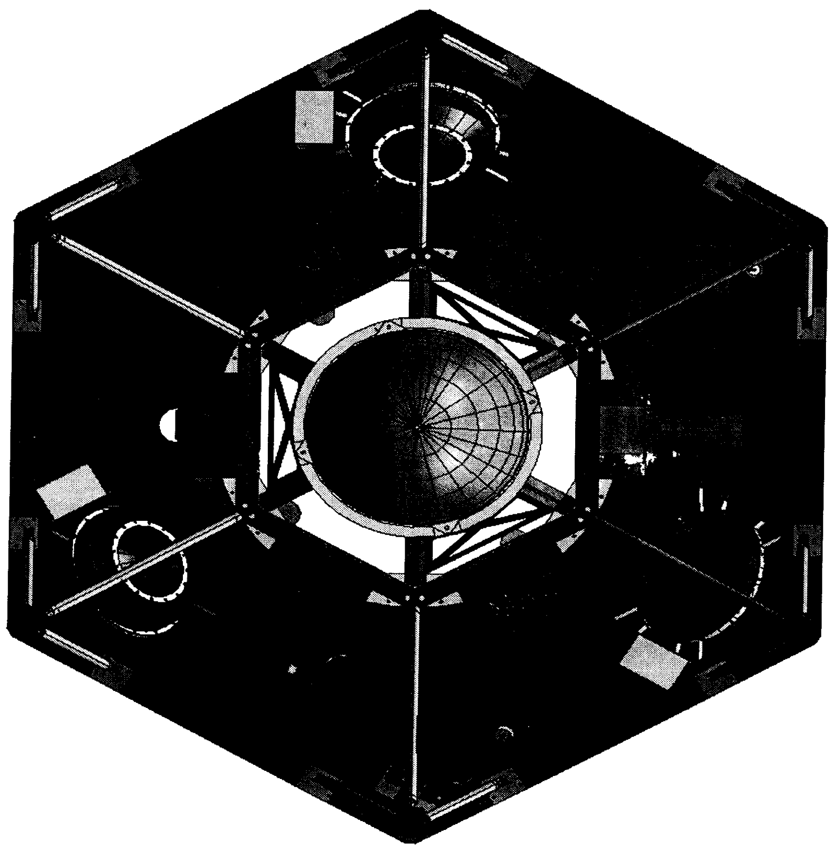


MAP Top View

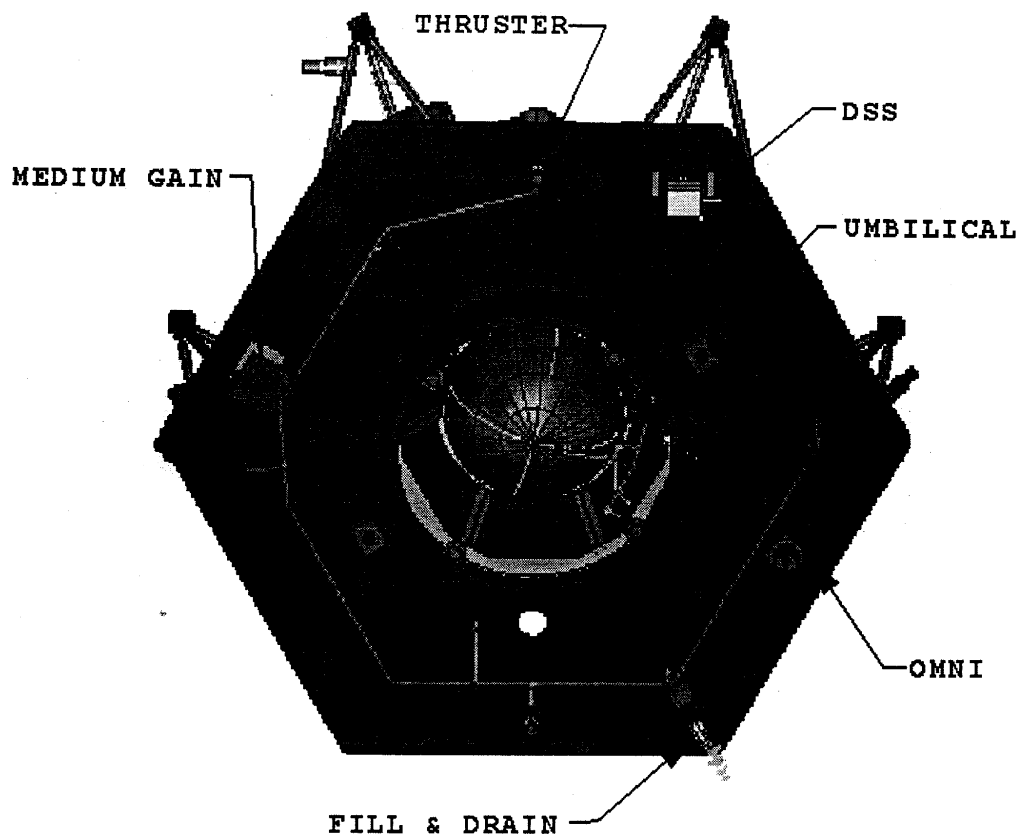



Bands:
K
Ka
Q
V
W
A
B
FEED HORNS
OMT
HYBRID TEE
COLD HEMT
WARM HEMT
PHASE SWITCH
FILTER
DETECTOR
Signal Channel
40 Signal Channels
Radiometer
20 Phase-Matched Radiometers
Differencing Assembly
10 Differencing Assemblies

MAP Top View

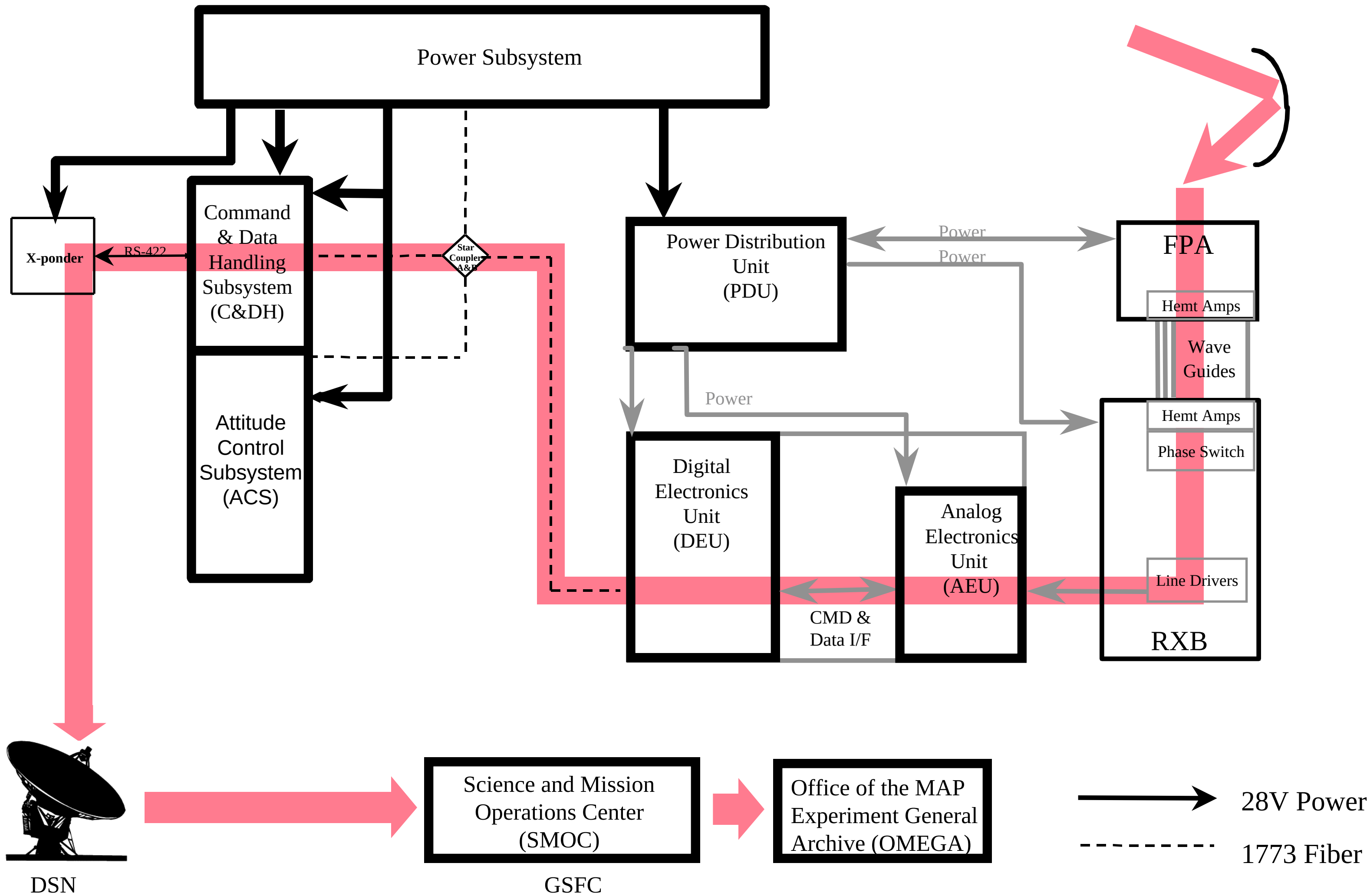


MAP Bottom Deck Components



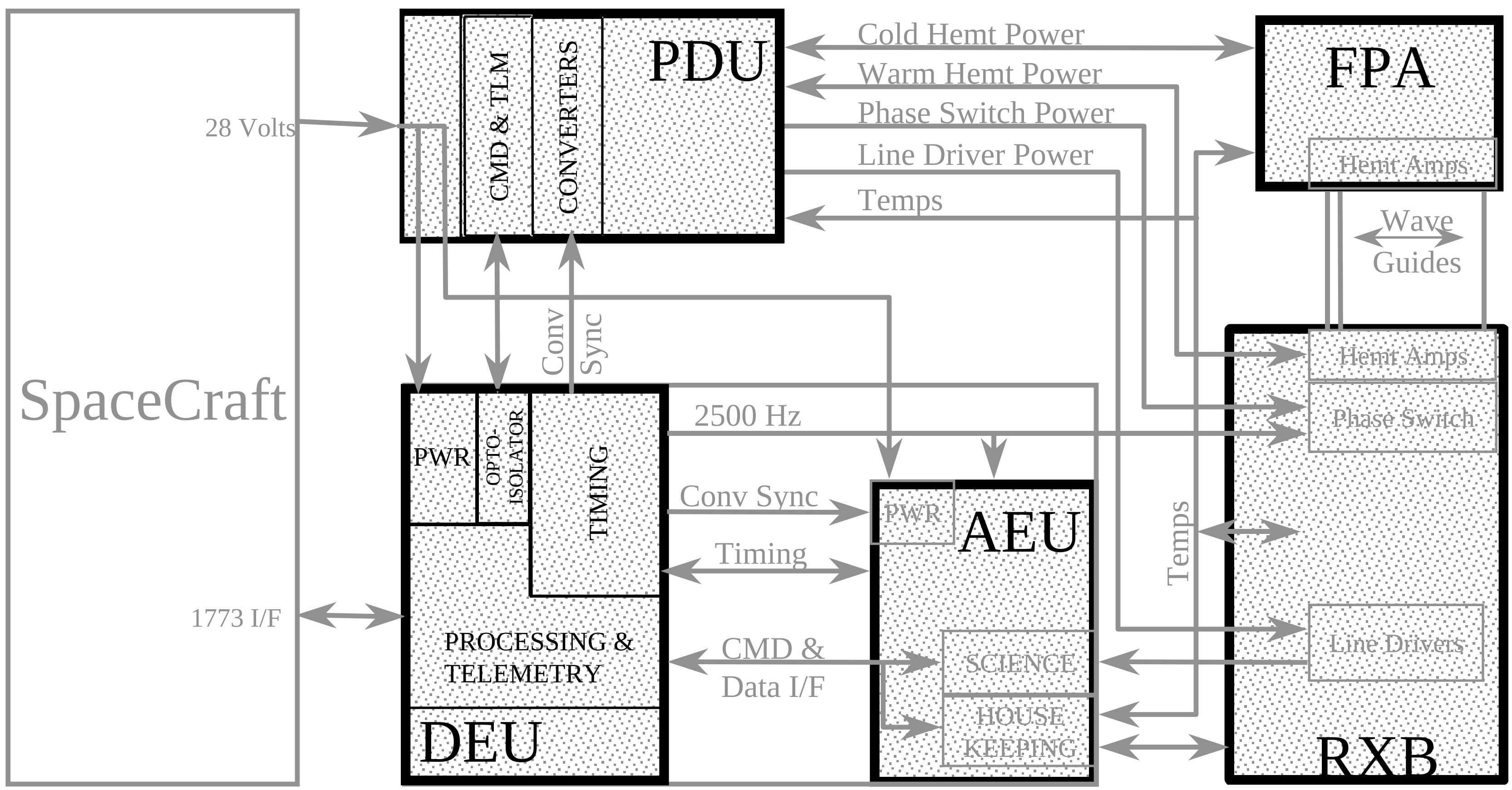
MAP Signal Flow

Systems Engineering



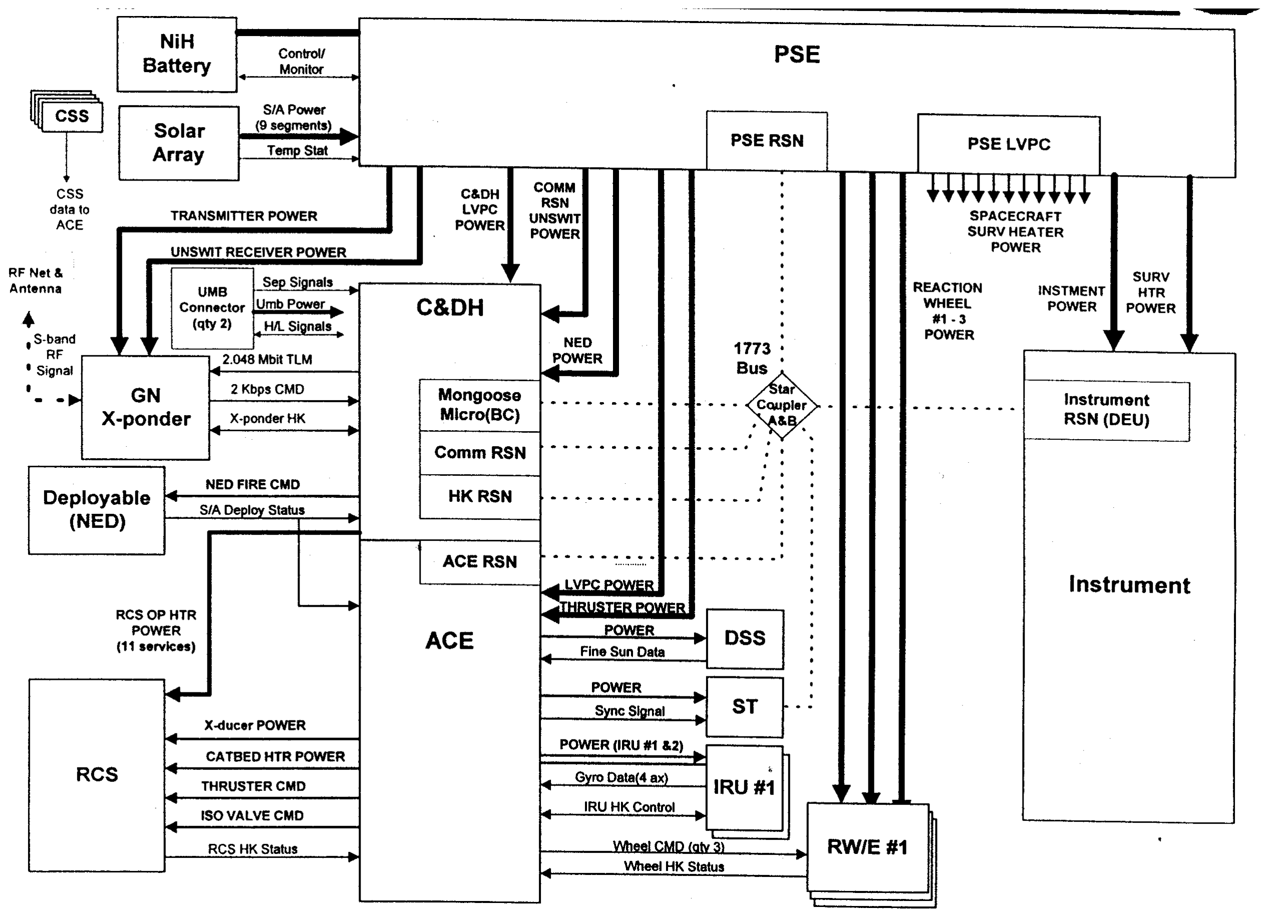
Instrument Electronics Block Diagram

Systems Engineering



Electrical System Design

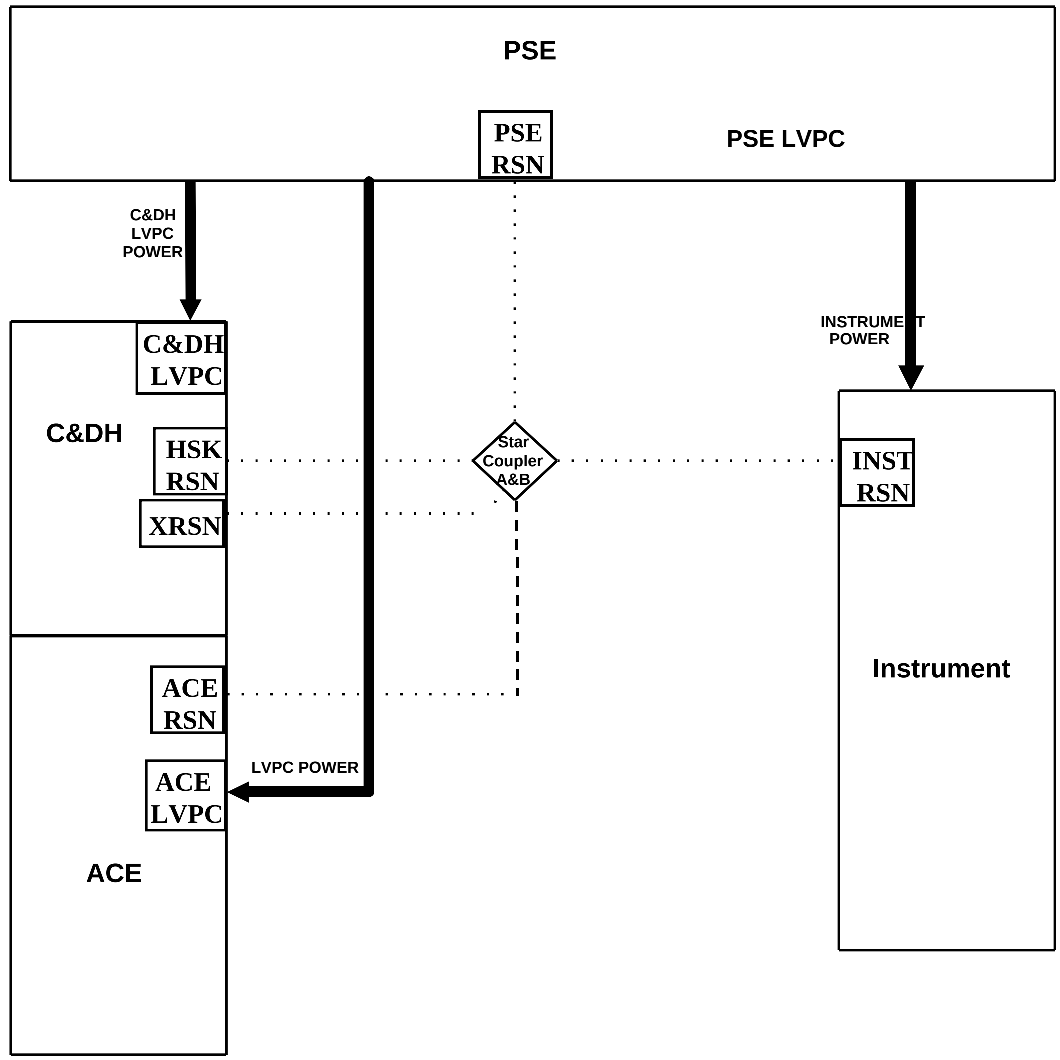
Systems Engineering



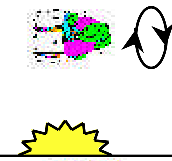
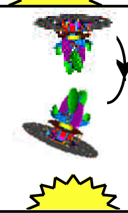
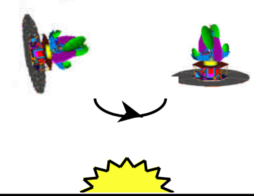
Standard
Power and Data Interfaces

Remote Services Node (RSN)
- Standard Data Interface
- Generic Services:
  1773 I/F
  Microprocessor and generic software
  Command decoding and distribution
  Telemetry collection and formatting
  Operating system and OS services
- User-specific applications
  1/2 card available for user h/w
  Application-specific software

Low Voltage Power Converter (LVPC)
- Standard Power Interface
- Power conditioning and distribution
- 28V interface to S/C power services
- Local +-5, 15 and 28V distribution



Mission Phases

Launch through second stage burn	L + 0.0 - L + ~13.7 min.	• Fairing separation at ~5 minutes • Battery discharging	
Coast	L + 13.7 - L + ~64.5 min.	• 0.5°/sec barbecue roll • Arrays normal to sun • Battery charging	
Separation through Acquisition	S + 0.0 - S + ~35.0 min.	• Solar arrays deploy • S/C separates ~180° from sun	
Phasing Loops	2-4 weeks	• Nominal 22.5° attitude except during maneuvers • Acquiring science data	
Cruise	~3 months	• Nominal 22.5° attitude • Acquiring science data	
Observing	>= 2 years	• Acquiring science data • Momentum unloading and station-keeping maneuvers • Nominal 22.5° attitude	

MAP Budgets and Resources

- Mass
- Power
- Propulsion
- Bandwidth
- Sensitivity
- Data Loss
- Spatial Resolution
- Systematic Error

MAP Mass Summary

WEIGHT SUMMARY			
	CURRENT	BUDGET	%
ITEM DESCRIPTION	WEIGHT	ALLOCATION	MARGIN
THERMAL REFLECTOR SYS	52.0	54.6	5.0
MICROWAVE SYSTEM	118.2	135.5	14.6
INSTRUMENT THERMAL	10.3	11.3	10.0
INSTRUMENT ELECTRONICS	46.5	53.5	15.0
INSTRUMENT HARDWARE	4.9	5.6	15.0
ACS	52.5	53.2	1.3
POWER	41.2	45.2	9.8
RF COMMUNICATION	7.2	7.9	9.0
C&DH	11.7	14.0	20.0
ELECTRICAL	36.5	40.2	10.0
PROPULSION	13.1	14.4	10.0
THERMAL	30.5	31.9	4.5
MECHANICAL	110.3	122.5	11.0
DEPLOYABLE	48.0	52.8	10.0
ATTACHMENT HARDWARE	5.1	5.6	8.8
INSTRUMENT SUBTOTAL	231.8	260.4	12.3
S/C DRY SUBTOTAL	356.2	387.6	8.8
Fuel/pressurant	41.3	45.0	9.0
Balance weight	10.0	10.0	0.0
OBSERVATORY TOTAL	639.3	703.1	10.0
AVAILABLE THROW WEIGHT	708.0		
CURRENT ESTIMATE	639.3		
TOTAL CONTING./RESERVE	68.7		
% TOTAL CONTING./RESERVE	10.7		

Mass Margin Management

- Analyzed margin required at the component level based on maturity
  - Estimated - 20% margin
  - Calculated - 10% margin
  - Prototype/engineering model - 5% margin
  - Flight hardware - 0% margin
- Developed margin release plan based on component development milestones
- Monthly tracking of subsystem mass estimates
- If margin available falls below margin required, a mass descope is triggered

MAP Mass Summary
6/10/97

WEIGHT SUMMARY ITEM DESCRIPTION	CURRENT WEIGHT	% EST.	% CALC.	% ENG. UNIT	% ACTUAL	BUDGET ALLOC.
Instrument Electronics	Kg					
PDU	24.50	39.00	61.00	0.00	0.00	3.41
AEU/DEU	22.00	50.00	50.00	0.00	0.00	3.30
TOTAL	**46.50**	**44.20**	**55.80**	**0.00**	**0.00**	**6.7**
Hardware						
TRS bolts	0.20	0.00	100.00	0.00	0.00	0.03
Microwave system bolts/brackets	4.70	90.00	10.00	0.00	0.00	0.71
TOTAL	**4.90**	**86.33**	**13.67**	**0.00**	**0.00**	**0.7**
INSTRUMENT BUS TOTAL	**227.94**	**27.23**	**60.06**	**10.99**	**1.58**	**27.4**
S/C BUS						
ACS						
(E) RW & RWE (3)	42.30	0.00	0.00	0.00	100.00	0.00
DSS & DSSE	1.60	0.00	0.00	0.00	100.00	0.00
CSS (6)	0.20	0.00	0.00	0.00	100.00	0.00
Star Tracker	4.75	0.00	100.00	0.00	0.00	0.48
Gyros	3.65	0.00	10.00	90.00	0.00	0.20
ACS TOTAL	**52.50**	**0.00**	**9.74**	**6.26**	**84.00**	**0.68**
C&DH						
C&DH/ACE (MAC)	11.70	55.20	0.00	44.80	0.00	2.34
C&DH TOTAL	**11.70**	55.20	0.00	44.80	0.00	**2.34**

Page 2

MAP Margin Release Plan

MAP WEIGHT SUMMARY 35490 ITEM DESCRIPTION	Control Mass (kg)	Apr-96	Jul-96	Oct-96	Jan-97	Apr-97	REQUIRED MASS CONTINGENCY (kg) Jul-97	Oct-97	Jan-98	Apr-98	Jul-98	Oct-98	Jan-99	Apr-99	Jul-99	Oct-99	Jan-00	Apr-00	Jul-00	Oct-00
Thermal Reflector System Total	49.00	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Thermal Components Total	10.30	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	0.52	0.52	0.52	0.00	0.00
Differencing assy	30.10	3.01	3.01	3.01	3.01	3.01	2.11	2.11	2.11	0.90	0.90	0.90	0.90	0.90	0.90	0.00	0.00	0.00	0.00	0.00
Feeds	10.28	1.29	1.29	1.29	1.29	1.29	1.29	0.51	0.51	0.51	0.51	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Absorber	4.00	0.40	0.40	0.40	0.40	0.40	0.28	0.28	0.28	0.12	0.12	0.12	0.12	0.12	0.00	0.00	0.00	0.00	0.00	0.00
Gamma Al. Cylinder	13.10	1.97	1.97	1.97	1.97	1.97	1.97	1.31	1.31	1.31	1.31	1.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FPA support structure	27.15	5.43	5.43	5.43	5.43	5.43	5.43	4.07	4.07	1.36	1.36	1.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RXB support structure	18.16	3.63	3.63	3.63	3.63	3.63	3.63	2.72	2.72	0.91	0.91	0.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PDU	24.50	3.68	3.68	3.68	3.68	3.68	3.68	3.68	2.45	2.45	2.45	1.23	1.23	1.23	0.00	0.00	0.00	0.00	0.00	0.00
AEU/DEU	22.00	3.30	3.30	3.30	3.30	3.30	3.30	3.30	2.20	2.20	2.20	1.10	1.10	1.10	0.00	0.00	0.00	0.00	0.00	0.00
Harness/Ground Strap Total	14.50	1.45	1.45	1.45	1.45	1.45	1.45	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.00	0.00	0.00	0.00
Instrument Brackets/Bolts Total	4.90	0.74	0.74	0.74	0.74	0.74	0.74	0.49	0.49	0.25	0.25	0.25	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00
ACS Total	52.50	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C&DH Total	11.70	2.34	2.34	2.34	2.34	2.34	2.34	0.59	0.59	0.59	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electrical Total	36.50	3.65	3.65	3.65	3.65	3.65	3.65	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83	0.00	0.00	0.00	0.00	0.00
RF Total	7.24	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.66	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Battery (NiH2)	21.40	2.14	2.14	2.14	2.14	2.14	2.14	2.14	2.14	2.14	1.07	1.07	0.00	0.00	0.00	0.00	0,00	0.00	0.00	0.00
Solar cells (6) -3.1 m~2	6.02	1.20	1.20	1.20	1.20	1.20	0.60	0.60	0.60	0.60	0.60	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PSE	13.73	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Propulsion Total	13.09	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	0.65	0.65	0.65	0.65	0.00	0.00	0.00	0.00	0.00	0.00
S/C Thermal Total	30.50	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	0.65	0.65	0.65	0.00	0.00
S/C Structure Total	92.38	9.24	9.24	9.24	9.24	9.24	9.24	9.24	9.24	9.24	9.24	4.62	4.62	4.62	0.00	0.00	0.00	0.00	0.00	0.00
S/C Bracketry Total	17.90	2.69	2.69	2.69	2.69	2.69	2.69	2.69	2.69	1.79	1.79	1.79	1.79	1.79	0.90	0.90	0.90	0.00	0.00	0.00
Deployable Total	48.01	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	2.40	2.40	2.40	0.00	0.00	0.00	0.00	0.00	0.00
S/C Bolts Total	5.14	0.77	0.77	0.77	0.77	0.77	0.77	0.51	0.51	0.26	0.26	0.26	0.26	0.26	0.00	0.00	0.00	0.00	0.00	0.00
Propellant Margin	0.00	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70
Total	584.10	63.78	63.78	63.78	63.78	63.78	62.16	53.66	51.33	43.33	41.60	30.99	22.42	22.42	10.90	6.49	5.76	4.87	3.70	3.70
Obeervatory Dry Total	584.10																			
Fuel/pressurant	41.30																			
Balance weight	10.00																			
OBSERVATORY TOTAL	635.40																			
AVAILABLE THROW WEIGHT	708.00																			
CURRENT ESTIMATE	635.40																			
TOTAL CONTING./RESERVE	72.60																			
% TOTAL CONTING./RESERVE	11.43																			

MAP Observatory Power Margins as a Function of Mission Phase (all powers in watts)	Go Int Power Through Separation	Post-Sep through Sun Acquisition	Safehold Mode @25°	Maneuver Mode @25°	Observing @22.5°
Continuous Mins per Phase	87.5	35.0	Indefinite	Up to 60	Indefinite
S/C Subsystems					
MAC					
C & DH & XRSN	20.3	20.3	20.3	20.3	20.3
ACE	7.1	7.1	7.1	7.8	7.1
ACS Components	45.0	105.0	80.0	80.0	80.0
Propulsion	15.3	15.3	0.3	48.6	0.3
Communications	34.0	34.0	34.0	34.0	34.0
Power	15.8	15.8	15.8	15.8	15.8
Harness	3.8	5.5	4.5	5.7	4.5
Thermal Control	12.6	24.4	21.0	21.0	21.0
Current Estimate	153.8	227.4	182.9	233.2	182.9
Allocated Contigency	12.8	32.9	14.4	1.6	14.4
% Contingency	8.3%	14.5%	7.8%	0.7%	7.8%
Budget Allocation	166.6	260.3	197.3	234.8	197.3

MAP Power Budget, Continued

Systems Engineering

MAP Observatory Power Margins as a Function of Mission Phase

(all powers in watts)

	Go Int Power Through Separation	Post-Sep through Sun Acquisition	Safehold Mode @25°	Maneuver Mode @25°	Observing @22.5°
Continuous Mins per Phase	87.5	35.0	Indefinite	Up to 60	Indefinite
Instrument					
FPA	0.0	0.0	2.5	2.5	2.5
RXB	0.0	0.0	18.1	18.1	18.1
PDU	0.0	0.0	41.4	41.4	41.4
AEU	0.0	0.0	76.0	76.0	76.0
DEU	0.0	0.0	5.3	5.3	5.3
Current Estimate	0.0	0.0	144.1	144.1	144.1
Allocated Contingency	0.0	0.0	28.8	28.8	28.8
% Contingency			20.0%	20.0%	20.0%
Budget Allocation	0.0	0.0	172.9	172.9	172.9
Observatory					
Current Estimate	153.8	227.4	327.1	377.3	327.1
Allocated Contigency	12.8	32.9	43.2	30.4	43.2
Margin to Power Avail	N/A	N/A	20%	4%	22%
Budget Allocation	166.6	260.3	370.2	407.7	370.2
Observatory Power Available			**392.4**	**392.4**	**400.0**
Source of Power Limit Estimate: 23Ahr	Battery Spec gives 300 W-Hrs @60% DOD		From arrays at 25°	From arrays at 25°	From arrays at 22.5°
Depth of Discharge At End	12.3%	41.0%		2%	
Margin vs. 60% DOD	79.5%	31.7%		96.0%	

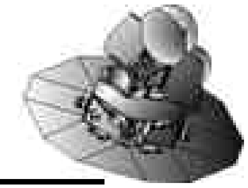
MAP Launch Power Budget

Systems Engineering

Below is the working, nominal launch case, July to Feb Launch.

				Total	**S/A Pwr**	**SpAx/**	**Batt**	**Batt**		**PSE**	**PSE**		**ACE**	**ACS Components**			**Propulsion**						
			Time	**S/C**	**Avail**	**SunAng**	**V**	**I**	**BSOC**		**Diss.**	**C&DH**	**+EVD**	**React**		**ST&**		**Thrust**	**Trans**		**Therm**		
	Mission Modes	sec	**min**	**Load**	Stowmin	149.4	Batt C=		23			**XRSN**	**logic**	**Wheel**	**IRU**	**DSS**	**CBHtr**	**EVD**	**pondr**	**Harn**	**Ctrl**	**NED**	**Other**
1	Go Internal P	start	-15	96.9	0	n/a	27.0	-4	100%	15.77	0.4	20.3	7.1	0	15	0	0	0	4	1.9	12.9	0	20.0
2	Launch	stop	0	96.9	0	n/a	27.0	-4	96.1%	15.77	0.4	20.3	7.1	0	15	0	0	0	4	1.9	12.9	0	20.0
3	End 1st Stage Burn		4.35	96.9	0	n/a	27.0	-4	95.0%	15.77	0.4	20.3	7.1	0	15	0	0	0	4	1.9	12.9	0	20.0
4	Fairing Sep	294	4.9	96.9	0	n/a	27.0	-4	94.8%	15.77	0.4	20.3	7.1	0	15	0	0	0	4	1.9	12.9	0	20.0
5	End 2nd Stage Burn		9.85	96.9	0	80	27.0	-4	93.5%	15.77	0.4	20.3	7.1	0	15	0	0	0	4	1.9	12.9	0	20.0
6	At Coast Attitude	820	13.7	96.9	0	85	27.0	-4	92.6%	15.77	0.4	20.3	7.1	0	15	0	0	0	4	1.9	12.9	0	20.0
7	Eclipse		22	96.9	0	85	27.0	-4	90.4%	15.77	0.4	20.3	7.1	0	15	0	0	0	4	1.9	12.9	0	20.0
8	Exit Eclipse		42	97.1	149	85	27.2	2	85.2%	15.77	2.9	20.3	7.1	0	15	0	0	0	4	1.9	13.1	0	20.0
9	CB Htrs On	3450	57.5	112.7	149	86	27.2	1	87.3%	15.77	3.2	20.3	7.1	0	15	0	15.3	0	4	2.3	13.0	0	20.0
10	Transmitter On	3750	62.5	143.3	149	85	27.0	0	88.0%	15.77	3.9	20.3	7.1	0	15	0	15.3	0	34	3.0	12.9	0	20.0
11	End Long Coast	3855	64.3	143.3	149	85	27.0	0	88.0%	15.77	3.9	20.3	7.1	0	15	0	15.3	0	34	3.0	12.9	0	20.0
12	At 3rd Stg Burn Att	3975	66.3	143.2	122	55	26.9	-1	88.1%	15.77	3.4	20.3	7.1	0	15	0	15.3	0	34	3.0	12.7	0	20.0
13	End 3rd Stage Burn	4050	67.5	143.2	122	55	26.9	-1	88.0%	15.77	3.4	20.3	7.1	0	15	0	15.3	0	34	3.0	12.7	0	20.0
14	SW Turn Wheels ON	4290	71.5	174.8	124	56	26.8	-2	87.8%	15.77	3.6	20.3	7.1	30	15	0	15.3	1	34	3.8	12.6	0	20.0
15	Yo Yo Despin Complete	4345	72.4	173.8	122	55	26.8	-2	87.7%	15.77	3.5	20.3	7.1	30	15	0	15.3	0	34	3.8	12.6	0	20.0
16	Separation	4350	72.5	173.8	122	55	26.8	-2	87.7%	15.77	3.5	20.3	7.1	30	15	0	15.3	0	34	3.8	12.6	0	20.0
17	Start NED/Wheels	4360	72.7	459.1	0	n/a	24.6	-19	87.7%	15.77	3.7	20.3	7.8	231.6	15	0	15.3	0	34	8.8	10.6	80	20.0
18	S/A Deploy Complete	4660	77.7	541.3	0	n/a	24.1	-22	80.9%	15.77	5.0	20.3	7.8	381	15	0	15.3	0	34	12.7	19.5	0	20.0
19	Wheels to 127W	4572	76.2	541.3	0	n/a	24.1	-22	83.3%	15.77	5.0	20.3	7.8	381	15	0	15.3	0	34	12.7	19.5	0	20.0
20	Max Wheel Power	4632	77.2	418.9	0	n/a	24.8	-17	81.7%	15.77	3.1	20.3	7.1	261	15	0	15.3	0	34	9.7	20.7	0	20.0
21	Rate Null/Wheel Despin	4752	79.2	243.5	0	n/a	24.7	-10	79.2%	15.77	1.2	20.3	7.1	90	15	0	15.3	0	34	5.5	20.5	0	20.0
22	CSS Acquisition Complete	6450	108	246.4	329	45	26.4	3	59.0%	15.77	7.3	20.3	7.1	90	15	0	15.3	0	34	5.5	23.4	0	20.0
23	Acquired (35min)	6610	108	247.4	443	25	26.9	7	59.0%	15.77	9.7	20.3	7.1	90	15	0	15.3	0	34	5.5	24.4	0	20.0
24	Steady State		200	234.6	443	25	28.5	7	100.0%	15.77	9.8	20.3	7.1	90	15	0	0	0	34	5.2	27.2	0	20.0

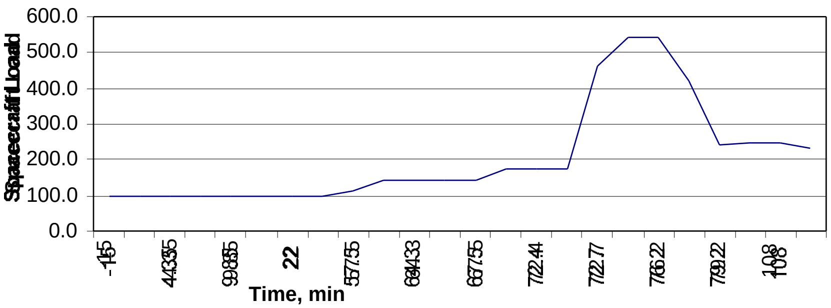
Max DOD= 41.0%



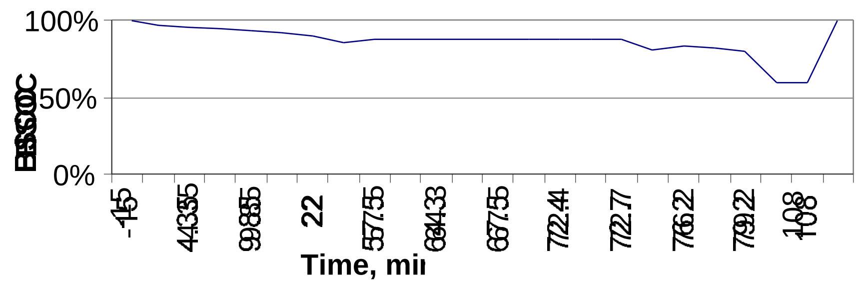
MAP Launch Power Profiles

Systems Engineering

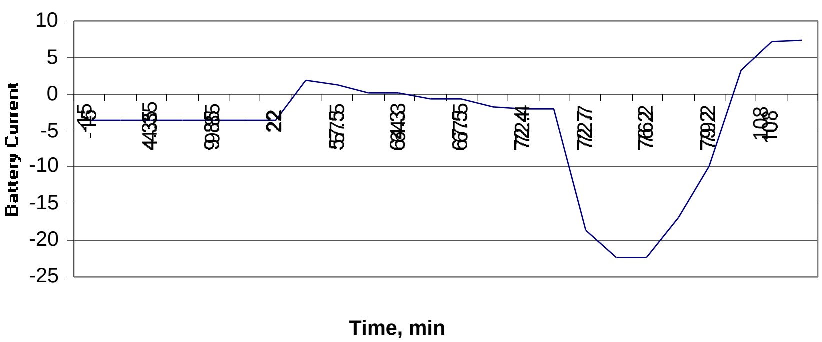
MAP Spacecraft Power Profile during Launch



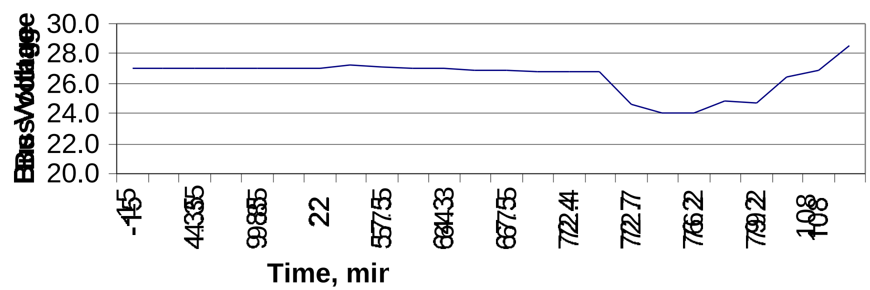
MAP Battery State of Charge during Laun



MAP Spacecraft Battery Current Profile during Launch



MAP Power Bus Voltage during Laun



Below is the maximum Correction Maneuver.

YAW1 Mission Modes	Time min	Total S/C Load	S/A Pwr Avail	SpAv/ SunAng	Batt V	Batt I	BSOC	PSE	PSE Diss.	C&DH XRSN	ACE +EVD logic	ACS Components React Wheels	IRU	ST& DSS	Propulsion CBHtr	Thruster EVD	Trans pondr	Harnes	Therm Ctrl	Instr	Other
					Batt C=		23														
1 ACS Attitude	-10	361.0	526	22.5	31.2	5	100%	15.77	12.4	20.3	7.8	51	15	14	15.3	0	40	4.8	12	145	20
2	-9	361.0	60	80	29.2	-10	100%	15.77	3.6	20.3	7.8	51	15	14	15.3	0	40	4.8	12	145	20
3 Start Thrusters	0	394.8	167	70	29.5	-8	90.9%	15.77	6.3	20.3	7.8	51	15	14	15.3	33	40	5.6	12	145	20
4 Thruster Maneuver	5	394.8	167	70	29.0	-8	87.1%	15.77	6.3	20.3	7.8	51	15	14	15.3	33	40	5.6	12	145	20
5 Assume 2 hr. maneuver.	10	394.8	167	70	29.0	-8	83.2%	15.77	6.3	20.3	7.8	51	15	14	15.3	33	40	5.6	12	145	20
6 Add 18 min to each end.	33	394.8	167	70	27.9	-8	65.5%	15.77	6.3	20.3	7.8	51	15	14	15.3	33	40	5.6	12	145	20
7	38	394.8	167	70	27.9	-8	61.5%	15.77	6.3	20.3	7.8	51	15	14	15.3	33	40	5.6	12	145	20
8	43	394.8	167	70	27.9	-8	57.5%	15.77	6.3	20.3	7.8	51	15	14	15.3	33	40	5.6	12	145	20
9	48	394.8	167	70	27.9	-8	53.5%	15.77	6.3	20.3	7.8	51	15	14	15.3	33	40	5.6	12	145	20
11	53	394.8	268	60	26.4	-5	49.5%	15.77	8.6	20.3	7.8	51	15	14	15.3	33	40	5.6	12	145	20
10	58	394.8	315	55	26.6	-3	47.1%	15.77	9.6	20.3	7.8	51	15	14	15.3	33	40	5.6	12	145	20
12	63	394.8	359	50	26.8	-1	45.7%	15.77	10.6	20.3	7.8	51	15	14	15.3	33	40	5.6	12	145	20
13	68	394.8	436	40	27.2	2	45.0%	15.77	11.6	20.3	7.8	51	15	14	15.3	33	40	5.6	12	145	20
14	73	394.8	493	30	27.5	4	45.8%	15.77	12.2	20.3	7.8	51	15	14	15.3	33	40	5.6	12	145	20
16	78	394.8	535	20	27.7	5	47.5%	15.77	13.0	20.3	7.8	51	15	14	15.3	33	40	5.6	12	145	20
15	83	394.8	550	15	29.7	5	50.0%	15.77	13.3	20.3	7.8	51	15	14	15.3	33	40	5.6	12	145	20
17	88	394.8	561	10	29.7	6	52.6%	15.77	13.6	20.3	7.8	51	15	14	15.3	33	40	5.6	12	145	20
18	93	394.8	569	0	29.8	6	55.3%	15.77	13.8	20.3	7.8	51	15	14	15.3	33	40	5.6	12	145	20
19	98	394.8	569	0	29.8	6	58.2%	15.77	13.8	20.3	7.8	51	15	14	15.3	33	40	5.6	12	145	20
20	121	394.8	569	0	29.8	6	71.4%	15.77	13.8	20.3	7.8	51	15	14	15.3	33	40	5.6	12	145	20
21 End Maneuver	126	394.8	569	0	29.8	6	74.3%	15.77	13.8	20.3	7.8	51	15	14	15.3	33	40	5.6	12	145	20
22 Steady State	168	394.8	569	0	31.2	6	98.5%	15.77	13.8	20.3	7.8	51	15	14	15.3	33	40	5.6	12	145	20
					MaxDOD=		55.0%														

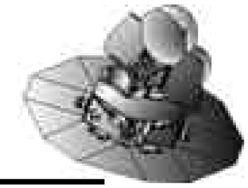
Propulsion Budget

Systems Engineering

Maneuver	ΔV	Propellant	Duration
Name	[m/s]	[kg]	[min]
Thruster Calibration	1	0.4	2
Maneuver for 20 min. launch slip	10	3.8	16
Phasing loop maneuvers before PF	30	11.1	56
Final perigee maneuver, PF	30	10.9	63
Correction maneuver after final perigee	15	5.4	34
Mid course correction, MCC	10	3.6	24
Stationkeeping for two years	8	4.1	28
Expulsion residuals		0.7	
Momentum management & spin down		1	
Line residuals		0.3	
Totals	**104**	**41.3**	**223**
Contingency for phasing loops	10	3.7	17
Totals with contingency ΔV	**114**	**45**	**240**

Assumptions:
- worst case delta-V trajectory fuel use
- 5% thruster inefficiency imposed
- steady state lsp 220 s (probably achieve 227)

Virtual Channels/Recorders?



Data Source	Function	RealTime VC	Recorder VR	Playback VC
Real Time	Health and Safety, Non Science	0	1	1
Events	Software Status/Events Messages	0	2	0
Processors	Memory, Table Dump	0	N/A	N/A
Science Tlm	Health and Safety, Non Science	0	1	1
Science	Map Science	N/A	3	3

System Record/Playback

3573	Instrument Record Rate BPS (VR3)
2750	S/C Record Rate BPS (VR1)
666667	Total RF Link Bit Rate BPS
3500	Assigned VC 0 Bit Rate BPS
750	Margin for VC0 Async BPS
563167	Playback Packet Bit Rate BPS (VR1, VR3)
9.1	24 Hr Science Playback Time Min
7.0	24 Hr S/C Tlm Playback Time Min

Telemetry Bit Rates

Systems Engineering

MAP VC0 Packet Summary

6/9/97

Interval / Rates

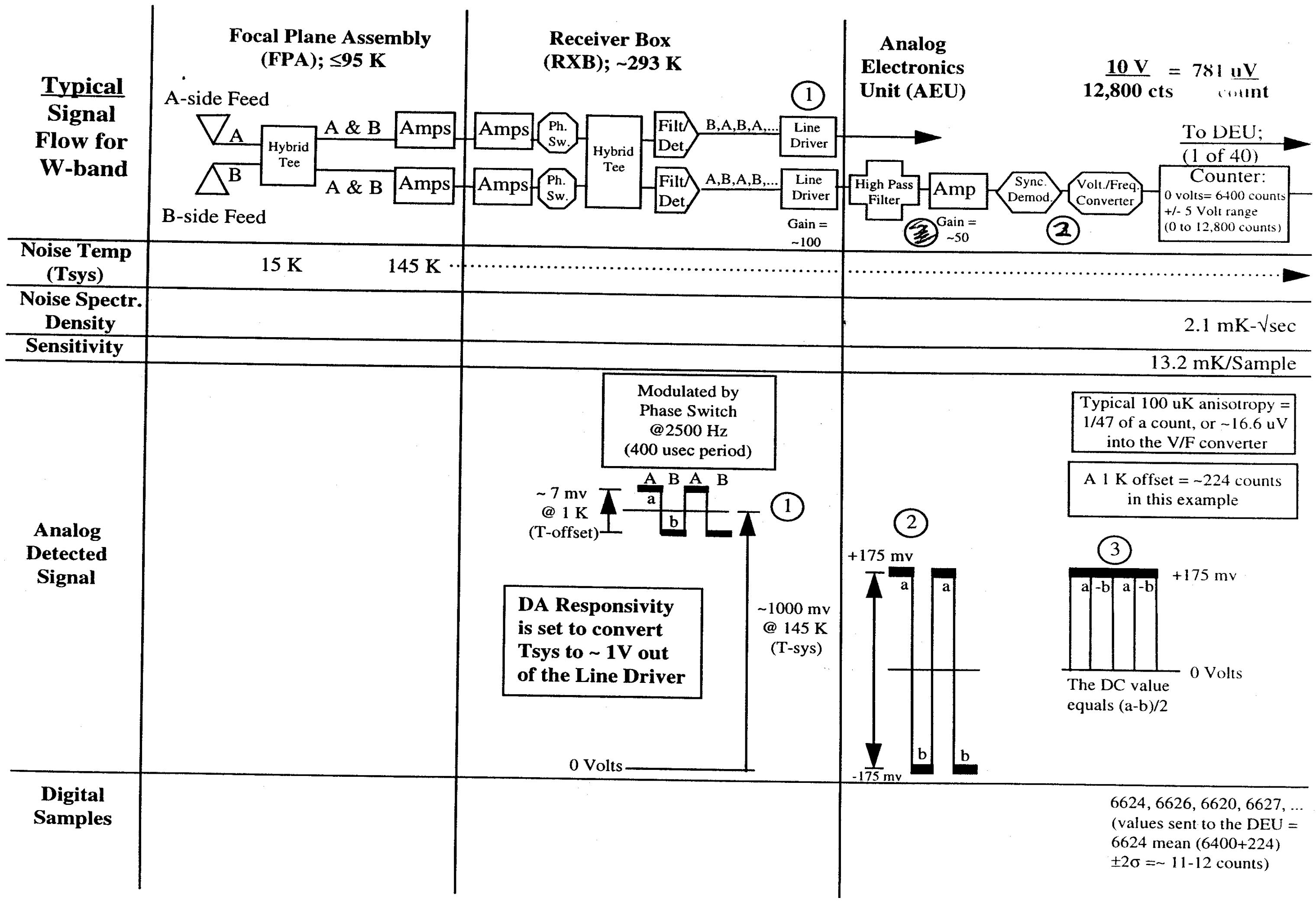
		Telemetry				Archive		
		Miss	Engr	Launch	TDRS	Miss	Engr	Launch
		1	2	3	4	1	2	3
	Allocation:	(2750)	(16000)	(16000)	(1700)	(2750)	(16000)	(16000)
Total Filter Bit Rate		2743	12533	12390	1580	2743	12533	12390
ACE Subsystem Filter Bit Rate	500	483	1539	1539	170	483	1539	1539
ACS S/W Subsystem Filter Bit Rate	900	980	4054	3550	391	980	4054	3550
CDH S/W Subsystem Filter Bit Rate	180	141	233	233	141	141	233	233
Comm Subsystem Filter Bit Rate	160	145	278	404	145	145	278	404
Deploy Subsystem Filter Bit Rate	10	8	63	252	252	8	63	252
Hskpng Subsystem Filter Bit Rate	290	94	252	300	90	94	252	300
Inst Subsystem Filter Bit Rate	150	175	189	237	45	175	189	237
Prop Subsystem Filter Bit Rate	10	9	1184	1184	148	9	1184	1184
PSE Subsystem Filter Bit Rate	200	158	211	259	158	158	211	259
Spare Subsystem Filter Bit Rate	350	550	4530	4432	40	550	4530	4432

Downlink Rates

CMD	BIT Rate Rate		Packet BPS	VC0 BPS	VC1 to VC3 BPS
4	1,200,000	Prime Mission L2 Rate 1/4 -2.4 dB	1,020,000	3,500	1,016,500
5	1,000,000	Prime Mission L2 Rate 1/4 -1.6 dB	850,000	3,500	846,500
6	857,143	Prime Mission L2 Rate 1/4 -0.9 dB	728,572	3,500	725,072
7	750,000	Prime Mission L2 Rate 1/4 -0.4 dB	637,500	3,500	634,000
8	**666,667**	**Prime Mission L2 Rate 1/4**	566,667	3,500	563,167
9	600,000	Prime Mission L2 Rate 1/4 +0.6dB	510,000	3,500	506,500
10	545,455	Prime Mission L2 Rate 1/4 +1.0 dB	463,637	3,500	460,137
12	461,538	Backup Mission L2 Rate 1/2	392,307	3,500	388,807
26	**222,222**	**Moon to Med Gain**	188,889	3,500	185,389
59	**100,000**	**Launch to Moon**	85,000	3,500	81,500
966	**6,205**	**Emergency Omni**	5,274	5,274	0
2999	**2,000**	**TDRS & Power on Default**	1,700	1,700	0
186	**32,086**	**I&T realtime, Realtime only**	27,273	27,273	0

Instrument Systems Overview

- Radiometer/AEU/DEU Signal Flow and Data Collection Overview
- Major Requirements Error Budgeting
  - Systematic Errors
  - Sensitivity
  - Spatial Resolution


Typical Signal Flow for W-band
Focal Plane Assembly (FPA); ≤95 K
Receiver Box (RXB); ~293 K
Analog Electronics Unit (AEU)
10 V / 12,800 cts = 781 uV / count
A-side Feed
A
B
B-side Feed
Hybrid Tee
A & B
A & B
Amps
Amps
Amps
Amps
Ph. Sw.
Ph. Sw.
Hybrid Tee
Filt/Det
Filt/Det
B,A,B,A,...
A,B,A,B,...
1
Line Driver
Line Driver
Gain = ~100
To DEU; (1 of 40)
High Pass Filter
Amp
Gain = ~50
3
Sync. Demod.
2
Volt./Freq. Converter
Counter:
0 volts= 6400 counts
+/- 5 Volt range
(0 to 12,800 counts)
Noise Temp (Tsys)
15 K
145 K
Noise Spectr. Density
2.1 mK-√sec
Sensitivity
13.2 mK/Sample
Analog Detected Signal
Modulated by Phase Switch @2500 Hz (400 usec period)
A B A B
a
b
~ 7 mv @ 1 K (T-offset)
1
DA Responsivity is set to convert Tsys to ~ 1V out of the Line Driver
~1000 mv @ 145 K (T-sys)
0 Volts
2
+175 mv
a
a
b
b
-175 mv
Typical 100 uK anisotropy = 1/47 of a count, or ~16.6 uV into the V/F converter
A 1 K offset = ~224 counts in this example
3
a -b a -b
+175 mv
0 Volts
The DC value equals (a-b)/2
Digital Samples
6624, 6626, 6620, 6627, ...
(values sent to the DEU = 6624 mean (6400+224) ±2σ =~ 11-12 counts)

- All 40 channels are integrated in the AEU and dumped to the DEU as 40 "<u>samples</u>" every 25.6 milliseconds
  - Greatly simplifies the design of the AEU by allowing identical circuit layouts to be used for every channel; only one board design is required, and only one set of timing interfaces is needed.
- "<u>Observations</u>" are created in the DEU by co-adding the appropriate number of 25.6 msec samples such that the spatial resolution and data rate drivers are balanced:

	Samples/ Observation	msec/ Observation	FWHM Beam (°)	Sampling Factor
– **K**	5	128.0	1.10	3.2
– **W**	2	51.2	0.22	1.6

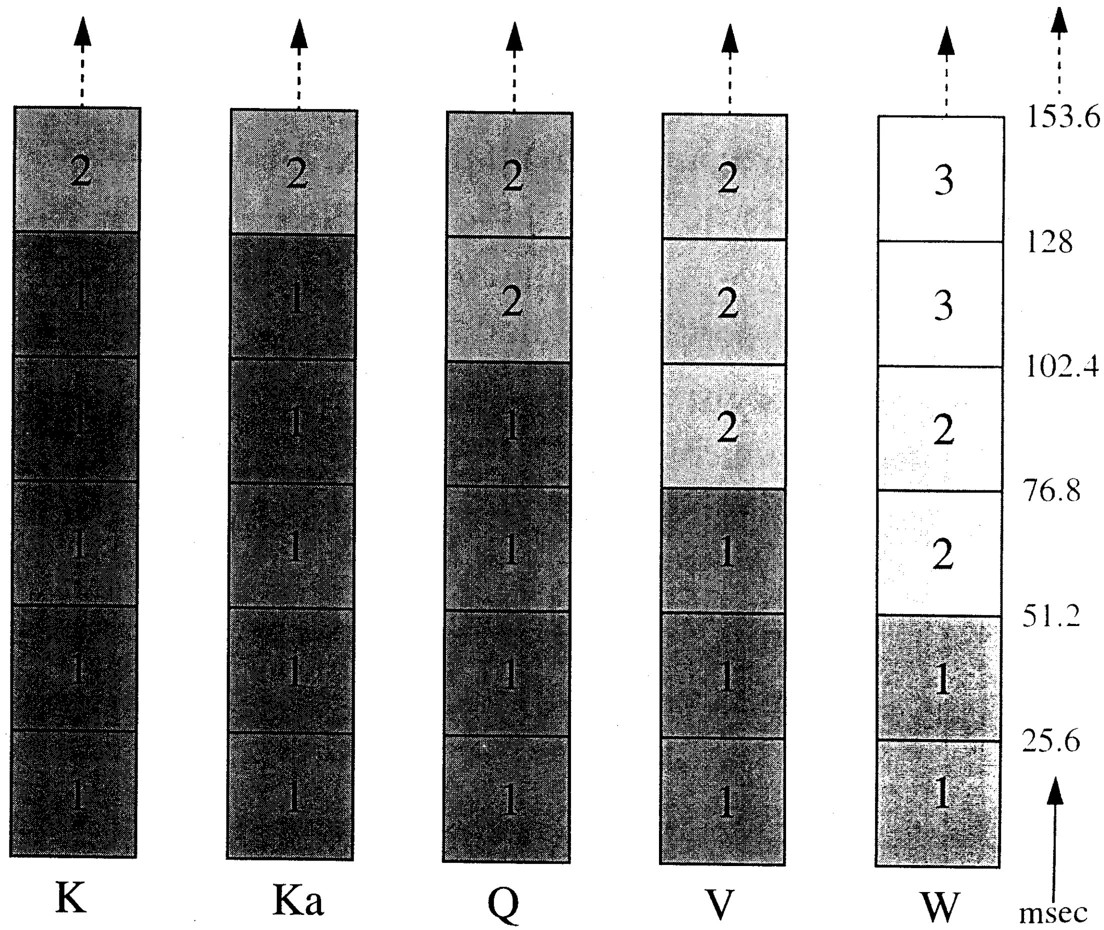
- A time-tagged "Science Packet" is formed every 1.536 seconds
  - Integral numbers of Observations are formed for each channel because the Samps/ Obs in each band (5(K,Ka), 4(Q), 3(V), 2(W)) all divide evenly into the 60 samples produced by each channel in 1.536 secs.
  - Observations collected in a science packet are sent to S/C for lossless compression

How Samples are Combined into Observations in Each Band

Systems Engineering

1) Each square represents a 25.6 msec Sample;

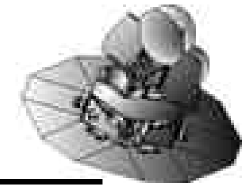
2) Adjacent squares of the same color/number are combined into one Observation;



Sensitivity is Not Sacrificed for Dynamic Range (W-band shown)

- Thermal fluctuation (rms) expected for one 51.2 msec Observation = ~9.3 mK
- We desire for this noise to exercise an average of 4 counts (rms)
- Therefore, 9.3 mK/4 counts = 2.33 mk/count is the sensitivity desired in each downlinked Observation
- Since we accumulate 2 W-band Samples/Observation, we can tolerate 1/2 the sensitivity per count for each Sample, or 2 x 2.33 = ~4.7 mK/count
- The resulting dynamic range for the 12,800 counts provided in the AEU A/D counter is therefore 12,800 counts * 4.7 mK/count = ~60 K, or +/- 30 K
- Note that co-adding "n" samples in the DEU to form an observation effectively multiplies the A/D counter range by "n", and therefore increases the dynamic range by "n" without degrading resolution.
- MAP's dynamic range (±20 to ±30 K) provides large margins against ever being off-scale once cold on-orbit.

MAP Timing Overview



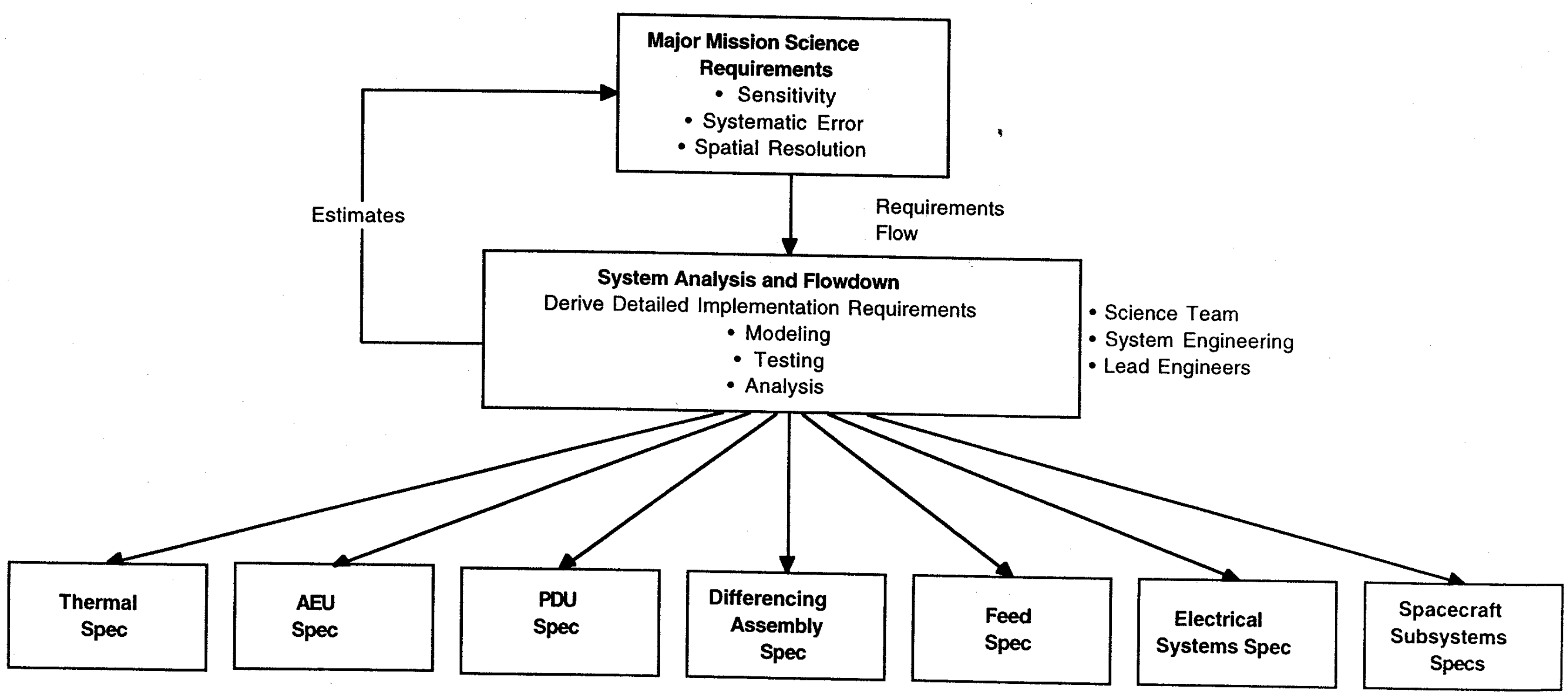
- A 24 MHz clock in the DEU is used to derive the master 1 MHz clock that is the basis for all of the Instrument's timing signals:
  - 1 MHz AEU V/F Converter Clock
  - 5000 Hz Blanking Pulses
  - 2500 Hz Phase Switch Clock
  - 39.0625 Hz Sample Pulses (i.e. 25.6 msec period)
- Data generation & collection for all 40 channels are synchronized using only these 4 clock signals
- Conclusion: MAP's timing is simple, and is especially easy to implement due to the uniform sampling approach adopted for all channels

Major Instrument Error Budgets

- Introduction
- Systematic Errors
- Sensitivity
- Spatial Resolution

Requirements Derivation Process

Systems Engineering



How Big is Our Haystack?
How Smallis our Needle?

• Noise Temperature (Tsys; W-band):	145,000,000 uK
• Cosmic Microwave Background (CMB):	2,728,000 uK
• CMB Dipole (0-peak):	3353 uK
• CMB Anisotropies (rms):	~100 uK
• MAP's Sensitivity Spec (rms):	20 uK
• MAP's Systematic Error Spec (rms):	4.5 uK

Systematic Error Introduction

- The key to MAP's success will be how well it controls Systematic Errors!
- "Systematic Errors" are temperature differences reported by MAP that are induced by non-random sources other than the CMB Anisotropies [and which do not average down with time as quickly as random noise does].
- We have three lines of defense:
  - #1 **Eliminate** systematic fluctuations that give rise to Systematic Errors
    - Drove our entire mission design, as previously discussed
  - #2 **Monitor** the systematic fluctuations **and correct** for the Systematic Errors
    - Slow drifts (~1 hour or longer) are removed by calibrating against the dipole
    - 0.5 mK monitoring of selected sensitive components is provided to bound/correct errors
    - RF bias monitoring of all 40 channels is provided to track gain fluctuations
    - Of most concern are **spin-synchronous errors**, as they most effectively mimic CMB signals
  - #3 **Filter and remove** the contaminated data

MAP's SPIN-SYNCHRONOUS "SYSTEMATIC ERROR" ERROR BUDGET
(Overview; Assumes 1 K Offset)

SYSTEMATIC ERRORS (uK; 1 sigma)	
Requirement [In the final map] :	4.5
Mapping Suppression:	x2
Allowed in the Data:	9.0
Est. Rollup (vs. allowed in data):	8.1

Additive Error
Δ Signal

Internal Emission Sources

Errors Due to SPIN-SYNCHRONOUS Common Mode and Differential TEMPERATURE VARIATIONS Acting on Fixed Emissivities

Estimate Rollup (uK) 4.5

- Applies to components **prior to amps** (i.e. reflectors, feeds, OMTs, WG, Hybrid Tees)
- Common mode temp rqts: <0.6-10 mK rms
- Differential mode temp rqts: <0.03-2 mK rms
- These temperature rqts apply at t-SPIN!

Additive Error
Δ Signal

External Emission Sources

Errors Due to SPIN-SYNCHRONOUS Sun, Earth, Moon, and Galactic SIGNAL VARIATIONS Acting on the Instrument Sidelobes

Estimate Rollup (uK) 4.0

- Drives Instrument-S/C shadowing rqt.
- Major impact on design of feeds
- Impacts spatial resolution via edge taper
- The above estimate assumes that the Galaxy contribution is corrected

Multiplicative Electronics Sources

Errors Due to SPIN-SYNCHRONOUS GAIN VARIATIONS Acting on the Fixed DA Radiometric Offset

Estimate Rollup (uK) 5.2

- Hybrid Tees and Phase Switches make differential and common mode distinctions irrelevant
- Drives 3.6 mK rms rqt on PDU and AEU
- Drives 0.5 mK rms rqt on RXB
- Drives 0.5 v p-p S/C Bus Voltage rqt.
- These stability rqts apply at t-SPIN!

Multiplicative Error
Δ Gain

Additive Error
Δ Signal

Additive Electronics Sources

Miscellaneous SPIN-SYNCHRONOUS Electronics Errors

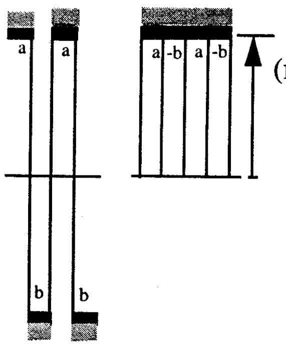
Estimate Rollup (uK) 1.2

- AEU post-demodulation amplifier offset variation
- Drives 3.6 mK rms rqt on AEU
- These stability rqts apply at t-SPIN!

MAP Confirmation Review   Instr-Sys Page 11   Rev-5; SSM/CEJ;6/17-19/97

Why Is It So Important to Mnimize A-Side/B-Side Signal Offsets?

Systems Engineering

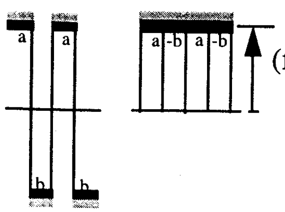


175 mV
(for an ~1K
W-band
Offset)

A 1% gain change will increase the size of both "a" and "-b" by 1.75 mV, and the DC output will increase by 1.75 mV.

With an A/D conversion of 781 uV per count, and a W-band transfer function (per sample) of ~4.7 mK/count, this represents a **10.6 mK** change in the temperature difference sensed.

Reducing the Offset between the A and B sides by a factor of 2 <u>doubles</u> MAP's immunity to gain variations!



87.5 mV
(for an ~0.5K
W-band
Offset)

A 1% gain change will increase the size of both "a" and "-b" by 0.875 mV, and the DC output will increase by 0.875 mV.

With an A/D conversion of 781 uV per count, and a W-band transfer function (per sample) of ~4.7 mK/count, this represents a **5.3 mK** change in the temperature difference sensed.

Excerpt From Systematic Error Detailed Budgets:

Multiplicative Systematic Errors

		D=Derived, P=Princeton, N=NRAO, G=GSFC, S=Specification							
Spin Synchronous Systematic Errors due to gain variations acting on the DA radiometric offset									
Parameter Definitions		dG/G=log gain fluctuations at t-spin			Toff=DA Radiometric offset				
FPA HEMT Amplifier Vdrain (2 units) [dV]	√2*dG/G*Toff	dG/G<	3.E-07	D	Toff<	1000	mK	0.5	uK
FPA HEMT Amplifier Vgate (2 units) [dV]	√2*dG/G*Toff	dG/G<	3.E-07	D	Toff<	1000	mK	0.4	uK
FPA HEMT Amplifier Temp (2 units) [dT]	√2*dG/G*Toff	dG/G<	0.E+00	D	Toff<	1000	mK	0.0	uK
FPA LED (2 units) [dI]	√2*dG/G*Toff	dG/G<	2.E-07	D	Toff<	1000	mK	0.2	uK
RXB HEMT Amplifier Vdrain (2 units) [dV]	√2*dG/G*Toff	dG/G<	3.E-07	D	Toff<	1000	mK	0.4	uK
RXB HEMT Amplifier Vgate (2 units) [dV]	√2*dG/G*Toff	dG/G<	2.E-07	D	Toff<	1000	mK	0.3	uK
RXB HEMT Amplifier Temp (2 units) [dT]	√2*dG/G*Toff	dG/G<	3.E-06	D	Toff<	1000	mK	4.7	uK
AEU Amp [dV]	dG/G*Toff	dG/G<	0.E+00	D	Toff<	1000	mK	0.0	uK
AEU Amp [dT]	dG/G*Toff	dG/G<	2.E-06	D	Toff<	1000	mK	1.8	uK
RXB Phase Switch [dT]	dG/G*Toff	dG/G<	5.E-09	D	Toff<	1000	mK	0.0	uK
RXB Phase Switch (Phase) [dI]	dG/G*Toff	dG/G<	2.E-06	D	Toff<	1000	mK	0.0	uK
RXB Phase Switch (Phase) [dT]	dG/G*Toff	dG/G<	7.E-05	D	Toff<	1000	mK	0.1	uK
RXB Diode Detector [dT]	dG/G*Toff	dG/G<	TBD		Toff<	1000	mK	TBD	uK
RXB Line Driver [dT]	dG/G*Toff	dG/G<	1.E-06	D	Toff<	1000	mK	1.0	uK
TOTAL (rss of this section)								**5.2**	**uK**

Excerpt From Systematic Error Detailed Budgets:

Multiplicative Systematic Errors

	(1/G)*(dG/dX)=Log gain-X(variable) coefficient				Spin Sync (rms): DV (Voltage), DI (current), & DT (temperature); all rms				a=absolute phase difference, a to b side			
dG/G=(1/G)*(dG/dV)*DV	<	6.6E-10	nV^-1	N	DV<	500.0	nV	S				
dG/G=(1/G)*(dG/dV)*DV	<	7.2E-10	nV^-1	N	DV<	400.0	nV	S				
dG/G=(1/G)*(dG/dT)*DT	<	0.0E+00	mK^-1	N	DT<	0.5	mK	S				
dG/G=(1/G)*(dG/dI)*DI	<	3.0E-08	nA^-1	P	DI<	5.0	nA	S				
dG/G=(1/G)*(dG/dV)*DV	<	5.5E-10	nV^-1	N	DV<	500.0	nV	S				
dG/G=(1/G)*(dG/dV)*DV	<	6.0E-10	nV^-1	N	DV<	400.0	nV	S				
dG/G=(1/G)*(dG/dT)*DT	<	6.7E-06	mK^-1	N	DT<	0.5	mK	S				
dG/G=(1/G)*(dG/dV)*DV	<	0.0E+00	mV^-1	G	DV<	0.18	mV	G				
dG/G=(1/G)*(dG/dT)*DT	<	5.0E-07	mK^-1	S	DT<	3.6	mK	S				
dG/G=(1/G)*(dG/dT)*DT	<	1.0E-08	mK^-1	P	DT<	0.5	mK	S				
dG/G=sin(a)(da/dI)*DI	da/dI<	1.0E-05	nA^-1	P	DI<	1.0	nA	S	a<	0.17	rad	P
dG/G=sin(a)(da/dT)*DT	da/dT<	8.7E-04	mK^-1	P	DT<	0.5	mK	S	a<	0.17	rad	P
dG/G=(1/G)*(dG/dT)*DT	<	TBD	mK^-1	P	DT<	0.5	mK	S				
dG/G=(1/G)*(dG/dT)*DT	<	2.0E-06	mK^-1	S	DT<	0.5	mK	S				

Excerpt From Systematic Error Detailed Budgets:

Offset Estimate

DA Radiometric Offset Estimate													
Parameter Definitions		dT=Ta-Tb B=2*(Ea-Eb)/(Ea+Eb)				E=average emissivity			T=average Temp				
Reflector (Pri. & Sec.) Temp Imbalance	dT*E	dT<	5000	mK	D	E<	0.0005	S		n.a.			5 mK
Reflector (Pri. & Sec.) Emissivity Imbalance	B*E*T	B<	0.20		P	E<	0.0005	S	T<	65000	mK	D	13 mK
Feed Temp Imbalance	dT*E	dT<	3000	mK	D	E<	0.007	S		n.a.			21 mK
Feed Emissivity Imbalance	B*E*T	B<	0.03		P	E<	0.007	S	T<	95000	mK	S	20 mK
OMT Temp Imbalance	dT*E	dT<	2000	mK	D	E<	0.008	S		n.a.			16 mK
OMT Emissivity Imbalance	B*E*T	B<	0.03		P	E<	0.008	S	T<	95000	mK	S	23 mK
Waveguide Offset Est. (0.1" length difference; 6" max length; 95K; 1% temp balance; 0.6 K/inch; Lyman Page Estimate)										95000	mK	S	95 mK
(Waveguide to Hybrid Tee Temp Imbalance)	dT*E	dT<	TBD	mK		E<	TBD			n.a.			mK
(Waveguide to Hybrid Tee Emiss. Imbalance)	B*E*T	B<	TBD			E<	TBD		T<	95000	mK	S	mK
Hybrid Tee Temp Imbalance	dT*E	dT<	500	mK	D	E<	0.05	P		n.a.			25 mK
Hybrid Tee Emissivity Imbalance	B*E*T	B<	0.03		P	E<	0.05	P	T<	95000	mK	S	143 mK
TOTAL (rss of the above)													**178 mK**
Used in Systematic Error Budgets:													**1000 mK**

Excerpt From Systematic Error Detailed Budgets:

Additive Systematic Errors

		D=Derived, P=Princeton, N=NRAO, G=GSFC, S=Specification												
#1) Spin Synchronous Temperature Fluctuation Effects (in the TRS/FPA)						At t-spin								
Parameter Definitions		E=average emissivity				dT=(Ta+Tb)/2 RMS DT=Ta-Tb RMS				B=2*(Ea-Eb)/(Ea+Eb)				
Primary and Secondary Reflectors: Common Mode dT RMS on fixed emmisivity difference	2*E*B*dT	E<	5E-04		S	dT<	10	mK	D	B<	0.2		P	2.0 uK
Primary and Secondary Reflectors: Differential DT RMS on Emissivity	2*E*DT	E<	5E-04		S	DT<	2	mK	D					2.0 uK
Feeds: Common Mode	E*B*dT	E<	0.007		S	dT<	2.2	mK	D	B<	0.03		P	0.5 uK
Feeds: Differential	E*DT	E<	0.007		S	DT<	0.13	mK	D					0.9 uK
OMTs: Common Mode	E*B*dT	E<	0.008		S	dT<	2	mK	D	B<	0.03		P	0.5 uK
OMTs: Differential	E*DT	E<	0.008		S	DT<	0.13	mK	D					1.0 uK
Waveguide to Hybrid Tee Common Mode	E*B*dT	E<	0.05		P	dT<	0.67	mK	D	B<	0.03		P	1.0 uK
Waveguide to Hybrid Tee Differential	E*DT	E<	0.05		P	DT<	0.04	mK	D					2.0 uK
Hybrid Tees: Common Mode	E*B*dT	E<	0.05		P	dT<	0.67	mK	D	B<	0.03		P	1.0 uK
Hybrid Tees: Differential	E*DT	E<	0.05		P	DT<	0.04	mK	D					2.0 uK
TOTAL (rss of this section)														**4.5 uK**
#2) Spin Synchronous Additive Electronics effects														
Parameter Definitions		G= K (observed) to V Transf. Function at V/F Counter Inp.				Sensitivity of Offset Voltage to DV or DT				DT or DV (rms) fluct. at t-spin				
AEU post-demod. electronic offset [dT]	G*(dV/dT)*DT	G=	5.9	uK/uV	S	dV/DT=	55	uV/K	G	DT<	0.004	K	S	1.2 uK
AEU post-demod. electronic offset [dV]	G*(dV/DV)*DV	G=	5.9	uK/uV	S	dV/DV=	8	uV/V	G	DV<	2E-04	V	G	0.0 uK
TOTAL (rss of this section)														**1.2 uK**
#3) Spin Synchronous Sidelobe Pickup effects														
Sun													P	0.001 uK
Earth													P	0.002 uK
(Uncorrected Galaxy; worst case K-band Shaped Optics)													G	(80) uK
Corrected Galaxy (Estimate ... TBR)													G	4.0 uK
Moon													P	0.001 uK
TOTAL (rss of this section)														**4.0 uK**

MAP Confirmation Review

Rev 6.SM CEJ 6/17-19 97

MAP's SENSITIVITY ERROR BUDGET OVERVIEW

COMPOSITE MAP SENSITIVITY*
(@ 0.3 deg x 0.3 deg pixels; 24 months of observing; (uK); 1σ)

Requirement:	**20.0**
Estimate Rollup:	19.9

40 GHz Map Sensitivity	
Estimate Rollup (uK):	28.8
• Instrument Sensitivity (uK):	27.3
• Impact of 10% Data Loss (multiplier):	1.054

60 GHz Map Sensitivity	
Estimate Rollup (uK):	36.8
• Instrument Sensitivity (uK):	34.9
• Impact of 10% Data Loss (multiplier):	1.054

90 GHz Map Sensitivity	
Estimate Rollup (uK):	37.2
• Instrument Sensitivity (uK):	35.3
• Impact of 10% Data Loss (multiplier):	1.054

* Major sensitivity-driven S/C requirements are to provide <95 K at the HEMTs, and 24 month mission life with <10% data loss.
* Of MAP's 5 bands, assume that only the 3 highest frequencies are combined in the final map (lowest 2 used for Galactic foreground removal only).
* Combining three maps improves the sensitivity by sqrt(3) (because the integration time increases by a factor of three)

MAPConfirmation Review Instr-Sys Page 17 Rev-6;CEJ;6/17-19/9

MAP's Temperature Sensitivity per Band (uK; 1 sigma)

Parameter	22 GHz	30 GHz	40 GHz	60 GHz	90 GHz
Sky	2.7	2.7	2.6	2.5	2.3
Reflector	0.05	0.05	0.06	0.08	0.1
Feed	0.5	0.5	0.5	1	1.5
OMT	2.3	2.3	2.3	4	6
Cold Magic Tee	3	3	4	4	5
First Cold HEMT Amp at 95 K	20	30	50	80	130
System Noise Temp (K) (Tsys; sum of the above; applies to each channel in a band)	29	39	59	92	145
Adjustment for sqrt(2) noise increase due to high-pass filtering (RF total power bias discarded); <u>ADJ1</u>	1.4	1.4	1.4	1.4	1.4
Adjustment for sqrt(2) noise increase (due to combining the noise from the A and B sides into one differential observation; <u>ADJ2</u>	1.4	1.4	1.4	1.4	1.4
Effective Bandwidth (BW_{eff}; GHz)	4	5	8	13	19
Number of Channels (Nch)	4	4	8	8	16
Integration time accumulated per channel after two years (for 0.3 deg x 0.3 deg pixels; Tau (secs))	160	160	160	160	160
Conversion to Thermodynamic Temperature (Alpha)	1.01	1.03	1.04	1.1	1.2
Adjustment for sqrt(2) noise reduction during the conversion of differential observations to relative A and B values during the map making process; <u>ADJ2'</u>	1.4	1.4	1.4	1.4	1.4
Estimated temperature sensitivity per band for 0.3 deg x 0.3 deg pixels after two years (uK;1 sigma)	25.5	31.4	27.3	34.9	35.3

Temperature Sensitivity = (Alpha * Tsys * ADJ1*(ADJ2/ADJ2')/ SQRT(BW_{eff} * Nch * Tau)

MAP's DATA LOSS ERROR BUDGET

AO-Allowed Mission Data Loss Over 2 Years at L2*	10%	Sources of Data Loss	Allocation	Corresponding Loss of Data
		Station keeping and Momentum Mgmt.	1.10%	~ 4 days of data per yr.
		On-board Data Transmission/Storage	0.55%	~ 2 day of data per yr.
		Downlink Transmissions Corrupting Simultaneous Science Observations	2.60%	37.5 min of data/day (downlink to 70m dish)
		Other Systematic Error Science Data Contamination	0.55%	~ 2 day of data per yr.
		Safehold Entries (SEUs, Failures, etc.)	1.64%	~ 6 days of data per yr.
		Ground Station Outages	0.27%	~ 1 day of data per yr.
		Downlink BER Losses	0.27%	~ 1 day of data per yr.
		Ground Handling Losses	0.55%	~ 2 day of data per yr.
		Unallocated Contingency	2.46%	
		Total	10.00%	

* A 10% loss reduces MAP's sensitivity per band by [(1/sqrt (90%))-1] , or ~5.4%

Note: Undetected data corruption is not considered credible given RS code and CRC in the data.

MAP's DERIVED ABSOLUTE TEMPERATURE REQUIREMENTS

- **The Temperature Requirements in this Table are Derived Directly from the Sensitivity and Systematic Error Budgets Previously Shown**

Steady State **Spin-Synchronous**

Steady-State

Sensitivity-Driven	
Component	**Bulk** K
FPA Components	<95

Steady State

Offset-Driven		
Component	**Bulk** K	**dT** K
Primary Reflectors	<65	5
Secondary Reflectors	<65	5
Feeds	<95	3
OMTs	<95	2
Cross-Coupling Waveguide	[<95]	[<0.7]
Hybrid Tees	<95	0.5

Spin-Synchronous Stability (rms)

Systematic Error Driven (Gain Variations)	
Component	**Common Mode** mK (rms)
AEU/DEU	3.6
PDU	3.6
FPA Amps	0.5
RXB Electronics	0.5

Spin-Synchronous Stabilty (rms)

Systematic Error Driven (Self-Emission Variations)		
Component	**Common Mode** mK (rms)	**Differential** mK (rms)
Primary Reflectors	10	2
Secondary Reflectors	10	2
Feeds	2.2	0.13
OMTs	2	0.13
Cross-Coupling Waveguide	[0.7]	[0.04]
Hybrid Tees	0.7	0.04

Spatial Resolution Overview

Systems Engineering

- Driven by W-band (MAP's shortest wavelength, 3.2 mm)
- Requirement: Achieve Spatial Resolution better than 0.3 degrees FWHM (i.e. 7.6 arc-min rms, per axis)
- Budget:

Budget	Estimates	Allocations
– Instantaneous Beam Size	5.1	6.7
– Beam Pointing Knowledge	0.9	1.8
– Azimuthal Beam Smearing	2.4	3.0
– Total(rss)	5.7	7.6
– Margin (rss)	5.0	

MAP's ON-ORBIT ABSOLUTE SPATIAL RESOLUTION ERROR BUDGET

(All values are **arc-min** and **1 sigma** unless otherwise indicated)

Previous Values	Item		Value
▼	**The spatial resolution of the highest frequency band shall be 0.3 deg (FWHM) or better ... Equivalent to 18 arc-min (FWHM), or 7.7 arc-min (1 sigma)**	**Requirement (arc-min;1 sigma)**	**7.6**
		Allocation Rollup:	**7.6**
		Estimate rollup w/ no beam smearing:	5.2
5.5	(Equivalent to 0.224 degrees FWHM)	Estimate rollup:	5.7
TBD	**Error Source #1: Instantaneous Beam Size (Absolute)**	Allocation:	6.7
	(Equivalent to 0.20 degrees FWHM)	Estimate rollup:	5.1
	Ideal Beam Size Design Parameters		
4.85	YRS Analysis of Flight Reflector and Feed Designs	5.11	
	Beam Size Uncertainties (rss with above)		
	Reflector Fabrication (upper limit: 2% of beam)	0.1	
	Feed Fabrication (upper limit: 5% of beam)	0.3	
0.5	Reflector/Feed Misalignments (based on STOP sensitivities and TRS/FPA alignment tolerances, the latest estimate for this error source is 0.1 arc-min)	0.5	
	Error Source #2: Beam Pointing (Knowledge)	Allocation:	1.8
		Estimate rollup:	0.9
	Pointing Knowledge Uncertainties (rss)		
	Instrument FOV (Beam) Boresighting relative to the ACS Star Tracker (using Jupiter data after one year)	0.1	
	Instrument/Star-Tracker Relative Pointing Stability [corresponds to +/- 25 K bulk temperature change]	0.5	
	ACS Pointing Knowledge (3-axis rss; downlink quaternions at one Hz; divide by sqrt(3) before rssing with other per-axis error sources)	1.3	
0.3	Error due to interpolating to determine pointing of individually time-tagged observations (Error already included in ACS Pointing Knowledge)	0	
0.15	Instrument Internal Observation Time Tag Relative Accuracy (@1 ms)	0.16	
0.15	ACS Internal Time Tag Relative Accuracy (@1 ms; already included in ACS Pointing Knowledge)	0	
0.15	Relative Accuracy between S/C time as acquired by the ACS and Instrument via their RSN's (@1 ms)	0.16	
TBD	**Error Source #3: Azimuthal Beam Smearing**	Allocation:	3.0
		Estimate rollup:	2.4
2.3	Azimuthal Integrate/Dump Beam Smearing (due to Observatory scanning motion)	2.4	

MAP Confir Instr-Sys Page 22 Rev-8;LP/CEJ;6/17-19/97

MAP's On-Orbit Absolute Pointing Accuracy Requirements/Budgets

(ABSOLUTE; degrees; 1 sigma)

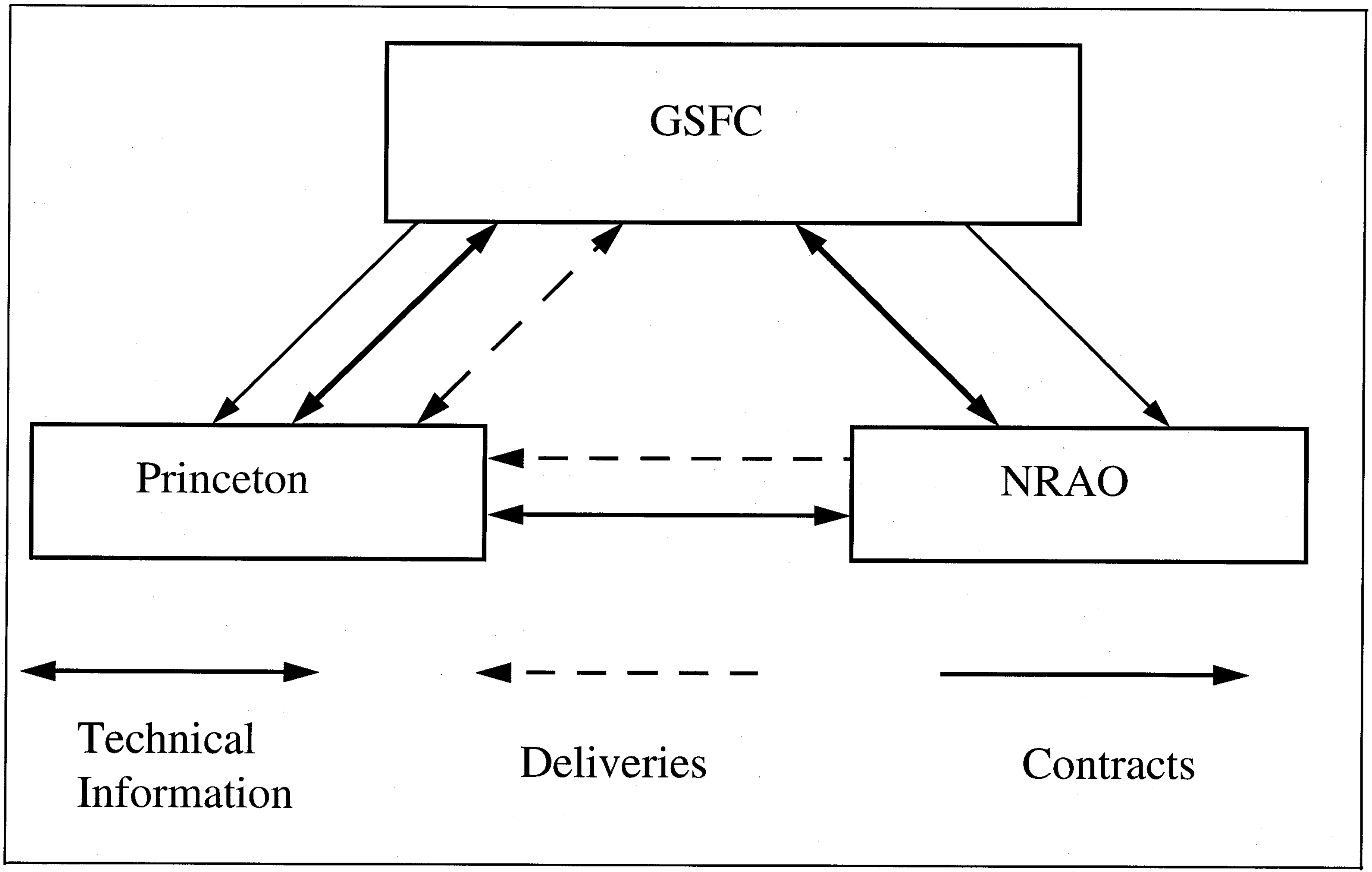
Azimuth: No tight pointing-driven requirements; the azimuthal angle between the A and B side central lines-of-sight shall be large to preserve large angular scale information.	Allocation:	180 +/- 2
	Estimated:	180 +/- 0.1
Elevation: Limit the A and B side central line-of-sight elevation errors relative to the spin plane to retain full sky coverage and avoid pointing the central lines-of-sight closer to the sun than planned.	Allocation:	0.6
	Estimated (rollup):	0.59
Error in the desired elevations of the A or B side central lines-of-sight relative to the S/C-Instrument interface plane:	0.5	
Tilts of the S/C-Instrument interface plane relative to the Z-axis of the S/C coordinate system (the ideal spin axis):	0.2	
Tilts between the actual spin axis and the ideal spin axis precessing on the ideal 22.5 degree half-cone:	0.25	

Electrical Systems

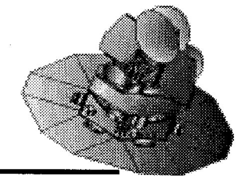
PRINCETON RESPONSIBILITIES

- Differencing Assemblies
- Feeds
- Optical Specifications
- Optical Testing
- Education & Public Outreach Coordination
- I&T Support at GSFC
- Data Analysis/Science

GSFC, PRINCETON, NRAO RELATIONSHIP



"PRINCETON" MAP TEAM



Physicists:

David Wilkinson
Lyman Page
Norm Jarosik
David Spergel
Michele Limon
Greg Tucker (Brown U.)
Mark Halpern (UBS)

Engineer:

Dick Bitzer

Mechanical Engineer:

Ted Griffith

Technicians:

Glenn Atkinson (mech)
3-man shop (mech)
Charlie Sule (elect)
Bob Sorenson (elect)
HEP Technicians (elect)

Business Management:

Susan Dawson
David Etherton
Gary Chehams

NRAO MAP TEAM

Engineers:

Marian Pospieszalski
Ed Wollack
Skip Thacker
Nancyjane Bailey

Mechanical Designer

Greg Morris

Management:

John Webber
Cathy Burgess
Jim Desmond
Kathy Whitcomb

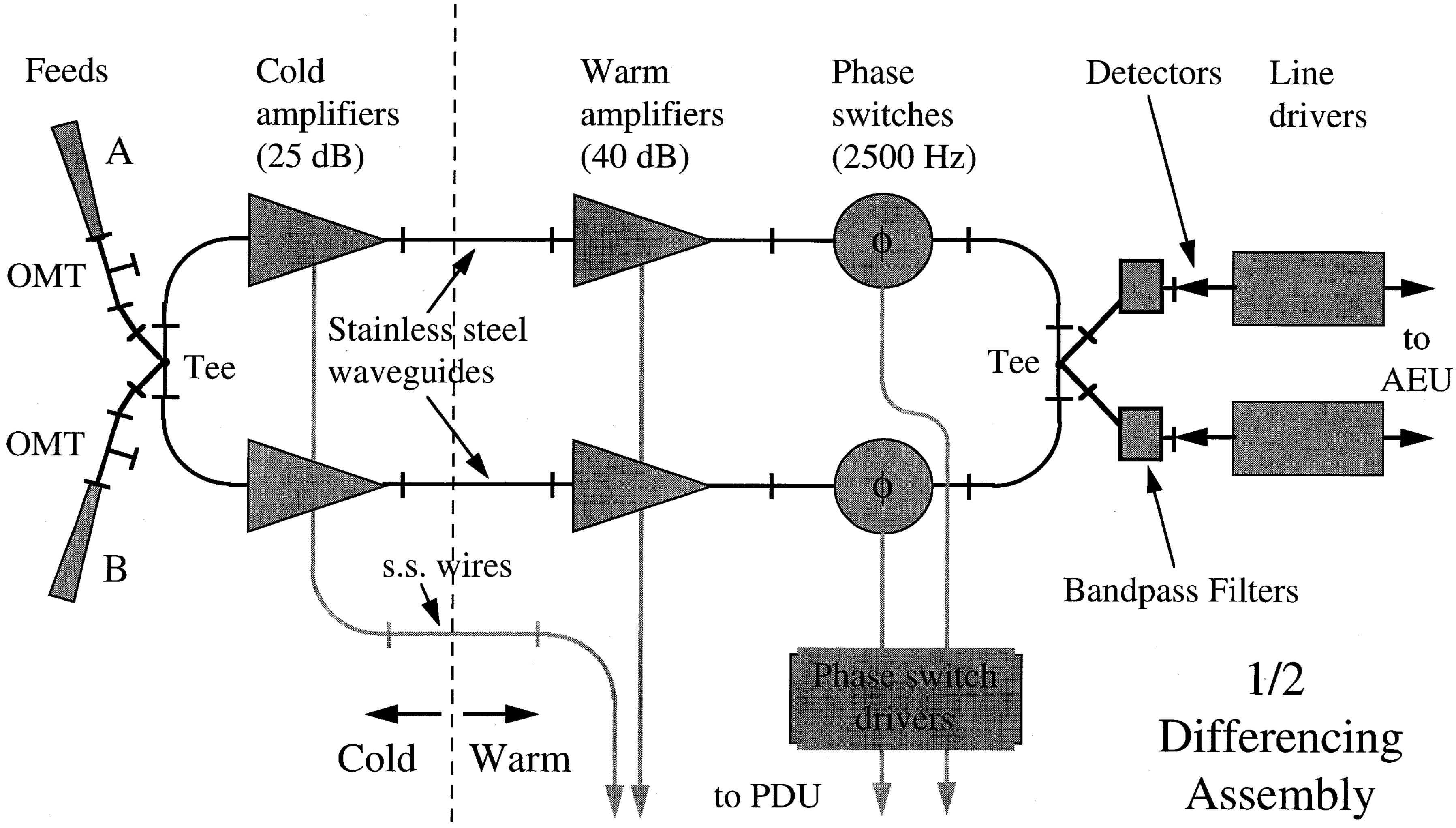
Technicians:

Bill Lakatosh
Bill Wireman
Ron Harris
Tod Boyd
Francoise Johnson

Machinisits:

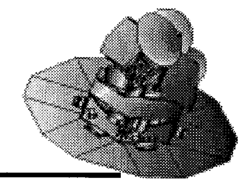
Matt Dillion
Tony Marshall

CORRELATION RECEIVER DESIGN



1/2 Differencing Assembly

WHY A CORRELATION RADIOMETER?



Science Drivers

- Re-measure large-scale anisotropy with good accuracy
- Minimize problems with baseline drift.

Technical Drivers

- Need "Dicke" switching to minimize effects of $1/f$ gain fluctuations in HEMT amplifiers. ($1/f$ works on system temperature in total power radiometer; in a correlation radiometer it works on the *offset* temperature, 100 times smaller.)
- Correlation technique avoids active components in sensitive areas of the radiometer. Front-end emission is small and stable

Trade-off

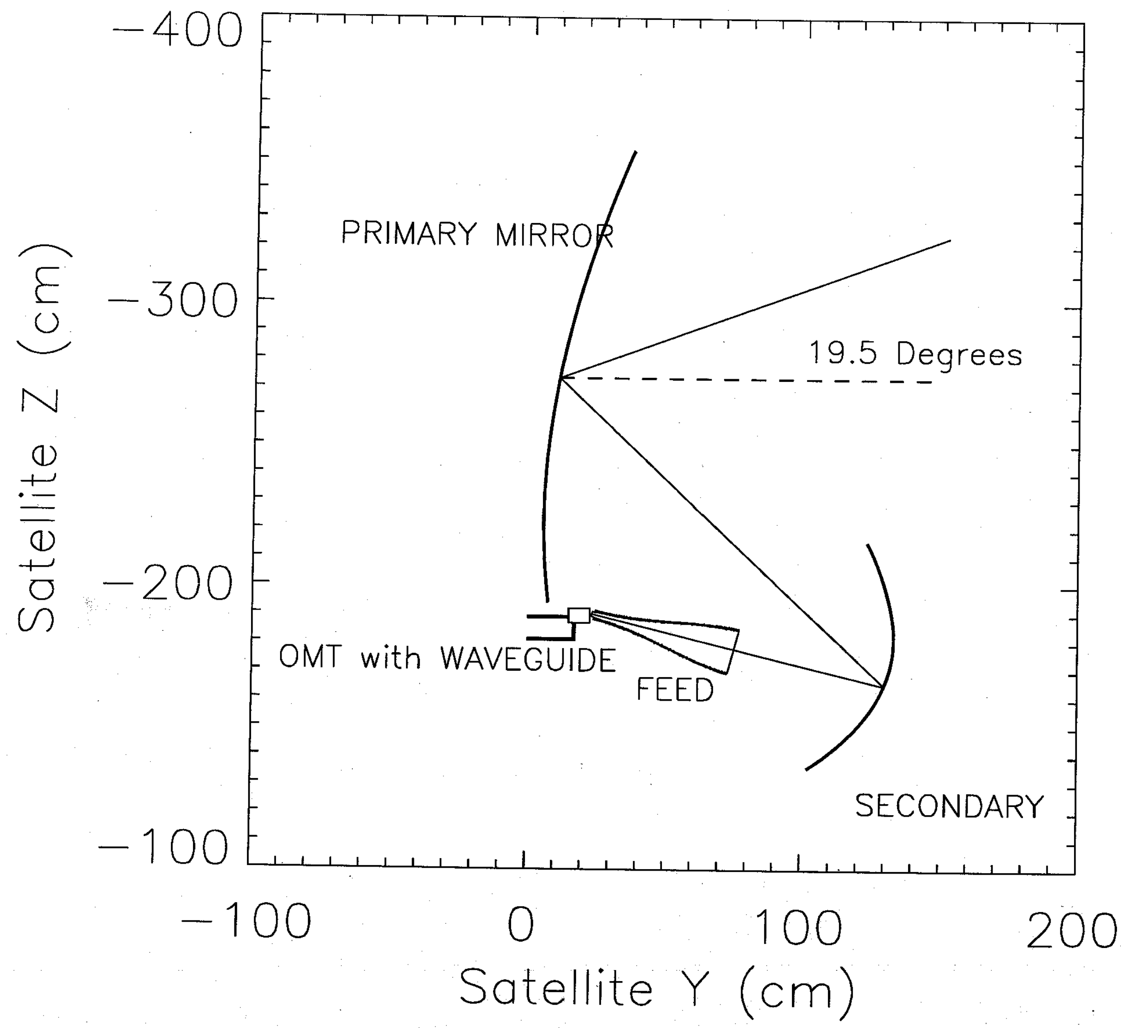
- More total failure modes than in 2 independent total power radiometers

STATUS OF RADIOMETER BUILD

- Q- and W-band prototype radiometers are operating in thermal/vacuum test chambers. Norm Jarosik will report. Overall performance is as expected from the correlation design.
- All flight parts for Q #1 are ordered. Assembly will begin with flight amplifier delivery. Q #1 will be delivered to GSFC 4.50 months later, or before.
- Current schedule driver is the Cu/SS waveguide.
- HEMT amplifier deliveries are a concern.
- Working closely with GSFC on mechanical and electrical interfaces.

MAP Confirmation Review

L. PAGE

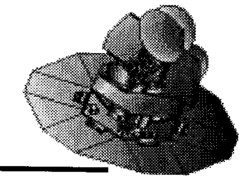


-400
-300
-200
-100
-100
0
100
200
Satellite Z (cm)
Satellite Y (cm)
PRIMARY MIRROR
19.5 Degrees
OMT with WAVEGUIDE
FEED
SECONDARY

OPTICS DESIGN - OVERVIEW

- Require differential system because of $1/f$ fluctuations in HEMT Amplifiers and Instrument
- To identify foreground emission (non-CMB), require broad spectral coverage with roughly equal sensitivity per frequency band. Have 5 frequency bands and 10 feeds per side
- Detect in two orthogonal polarizations
- Design for 0.5° resolution in Q band (40 GHz)
  0.2° resolution in W band (90 GHz)
- Optics must fit inside 108" (2.4m) diam. shroud
- Bases of feeds must be near each other
- Require very low sidelobe pickup to minimize signal from Sun, Earth, Moon, and Galaxy

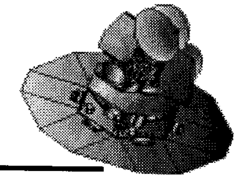
BASIC OPTICAL DESIGN



- Use shaped reflectors in Gregorian geometry with corrugated feeds

	K	Ka	Q	V	W
f(GHz)	**20-25**	**28-37**	**35-46**	**53-69**	**82-106**
#FEEDS/SIDE	**1**	**1**	**2**	**2**	**4**
EDGE TAPER(dB)	**-13**	**-20**	**-21**	**-21**	**-20**
RESOLUTION	**1.1°**	**0.65°**	**0.53°**	**0.31°**	**0.22°**

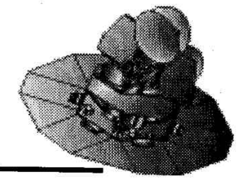
DESIGN PATH



- *YRS Associates and L. Page analyzed dozens of configurations including Cassegrain configuration, pure conic Gregorian, Abbe-sine shaping, aperture shaping
- YRS and YRS code used for final optical design (Code has been used on TDRSS & DSN)
- YRS & YRS code to design feeds
- YRS code to compute beam shapes and main sidelobes
- Use IDL code to analyze beams and geometry
- <u>DESIGN OF OPTICS IS DONE</u>

*YRS Associates: Vic Galindo, Bill Imbriale and Yahya Rahmat-Samii

VERIFICATION OF YRS CODE FOR OVERALL SYSTEM

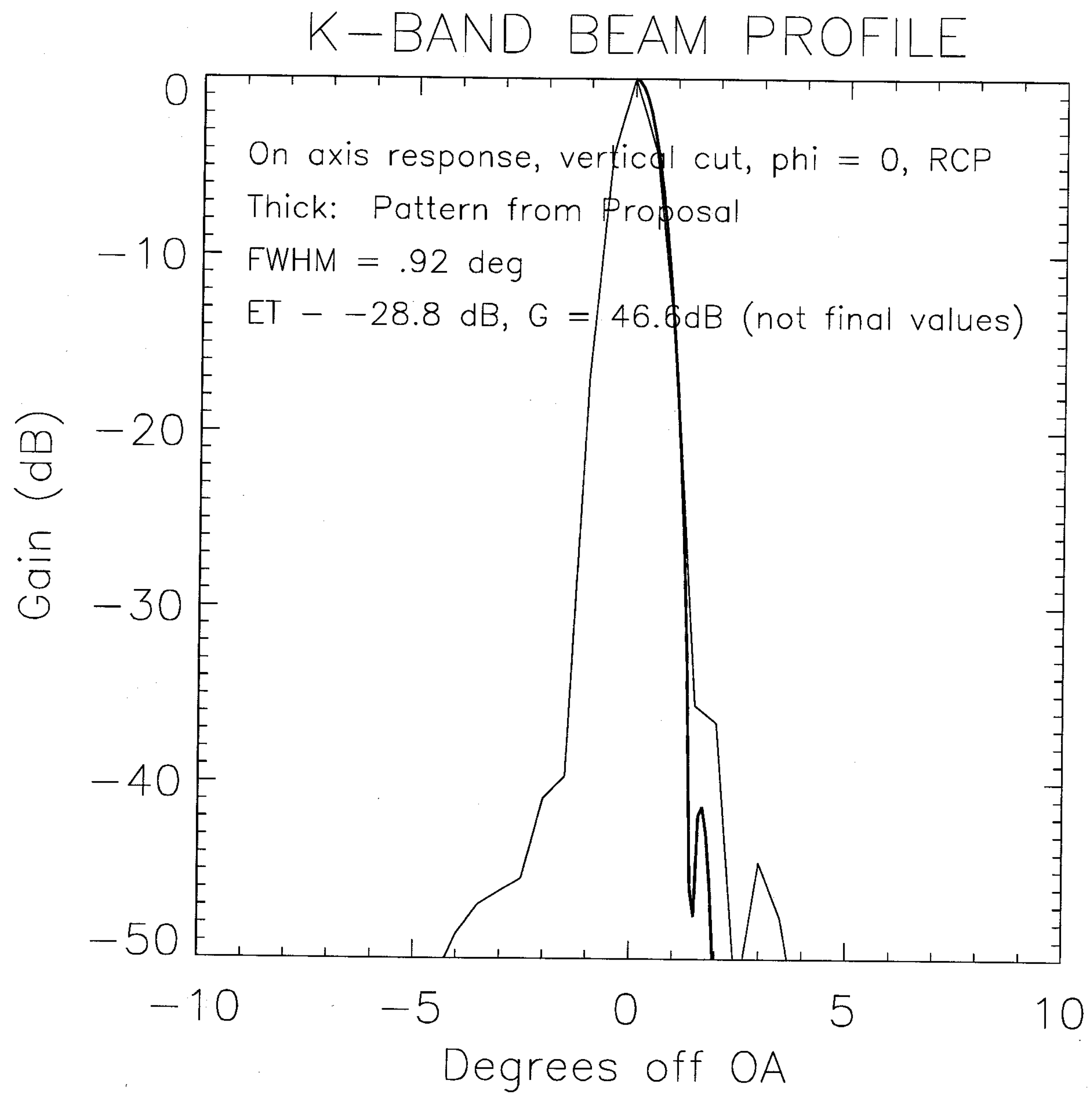


Microwave Optics

- With conic design, use same feed pattern in aperture integration code and recover same pointing and beam width

	θ_X(Az)	θ(El)	BEAM
YRS	**2.1**	**-2.7**	**~0.9°**
AI	**2°**	**-2.5**	**~0.9°**

- a) Constrain YRS "Shaping Code" to produce conic design with unknown parameters b) Fit parameters c) Feed into Code V with Cathy Marx at GSFC (Code V cannot do diffraction) d) Compare pointing to YRS output
- Code considered verified to reasonable level



K–BAND BEAM PROFILE
On axis response, vertical cut, phi = 0, RCP
Thick: Pattern from Proposal
FWHM = .92 deg
ET – –28.8 dB, G = 46.6dB (not final values)
Gain (dB)
0
–10
–20
–30
–40
–50
–10
–5
0
5
10
Degrees off OA

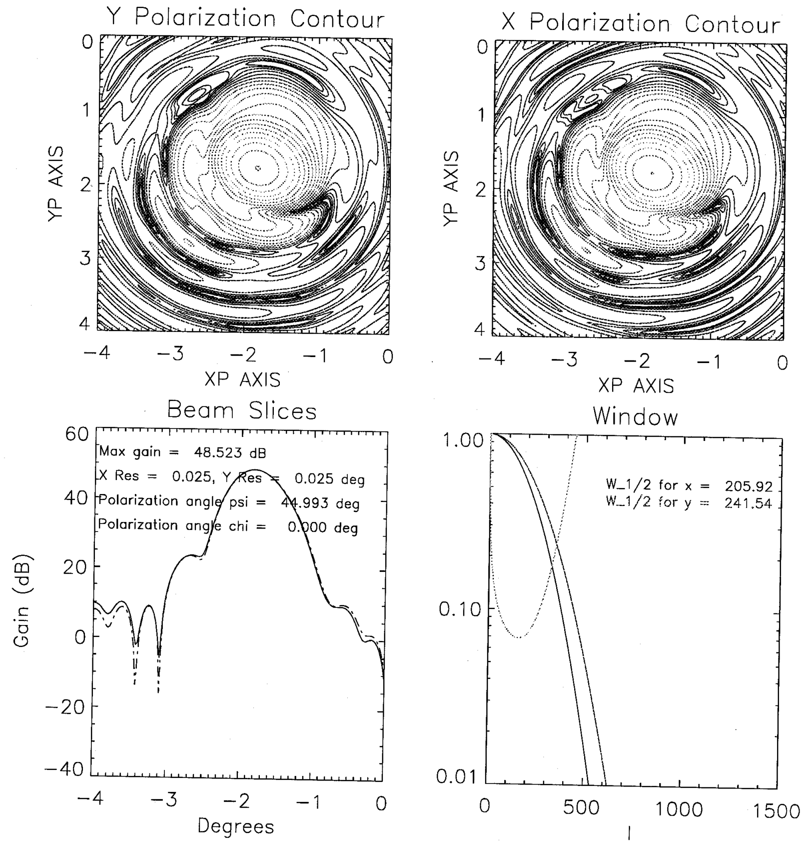
MAIN BEAM ANALYSIS

- Track -3, -6, -15, -20 dB beam widths in two dimensions. Track integral over beam, beam efficiency, gain, polarization, and window function
- Track current density on main and sub for edge taper and positioning
- Track 3-D geometry to make sure system fits togther in regards to:
    - Position of waveguide
    - Shadowing of feeds
    - TRS structure

h3p0q35.spw mainoff_u10.dat 35. GHz

dadra.dat acontr.dat

NDXM = 96 NDXS = 218



θ_m	−3dB	−6dB	−15dB	−20dB
X Beam−1.825	0.544	0.765	1.182	1.346
% Asym	4.220	5.619	8.373	9.026
Y Beam 1.775	0.464	0.648	0.994	1.144
% Asym	−4.352	−4.890	−7.827	−10.002
X/Y Asym	15.888	16.585	17.297	16.260

(XS,YS,ZS) = 0.00000 114.40212 0.00000

(AS,BS,GS) = 0.00000 −19.92000 0.00000

Beam max at (THTBPD,PHIBPD): (2.546, 135.796)

Integral over contour plot = 0.4943

Integral above gain−20 dB = 0.4837

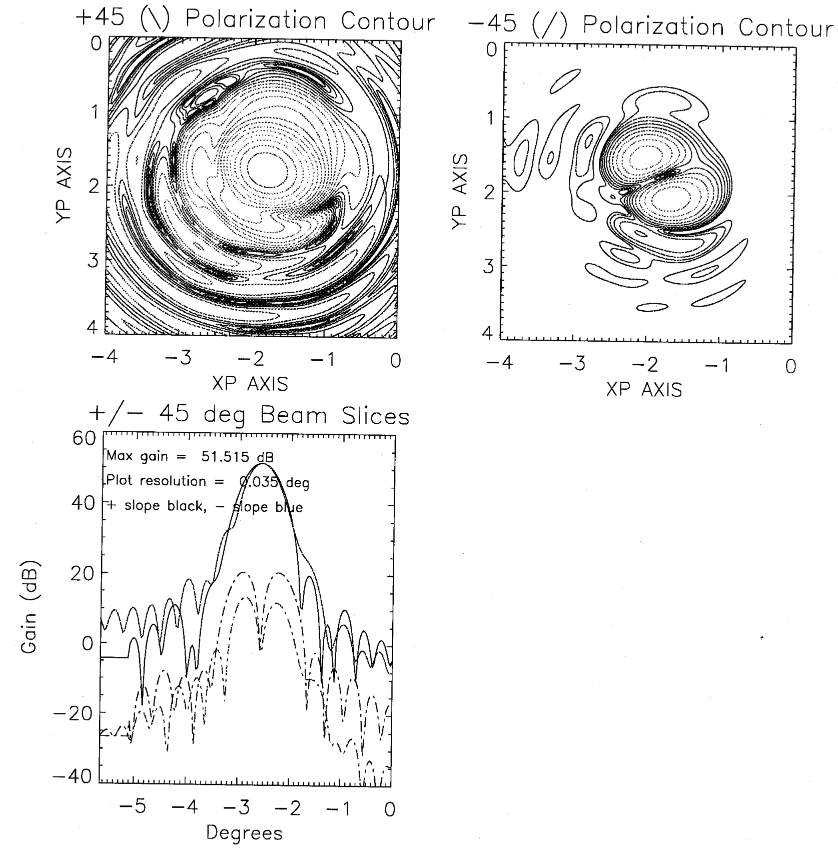
Integral above gain−40 dB = 0.4937

Beam efficiency 2.5 gmFWHM = 0.4935

Min at 2.5 =−20.24 dB, Max at 2.5 = 15.11 dB

(XF,YF,ZF) = −7.20000 8.80000 7.00000

(AF,BF,GF) = 44.00000 18.00000 265.67001



	θ_m	−3dB	−6dB	−15dB	−20dB
+ Beam	−1.825	0.532	0.747	1.148	1.298
% Asym		−0.059	0.245	−0.106	−0.895
− Beam	1.775	0.472	0.661	1.034	1.362
% Asym		5.372	5.856	7.541	−3.654
+/− Asym		11.956	12.242	10.411	−4.776

Beam max at (ELBPD,AZBPD): (17.716, −1.915)
Integral over contour plot = 0.9871
Beam efficiency 2.5 gmFWHM = 0.9856

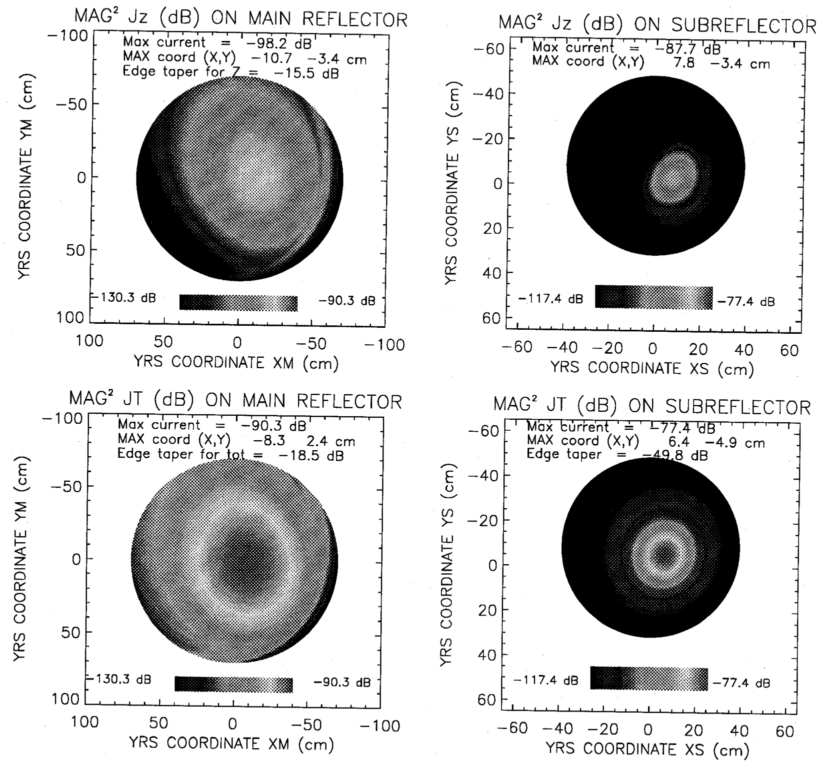
h3p0q35.spw mainoff_u10.dat 35. GHz

dadra.dat file39.dat

(XS,YS,ZS) = 0.00000 114.40212 0.00000 (XF,YF,ZF) = −7.20000 8.80000 7.00000

(AS,BS,GS) = 0.00000 −19.92000 0.00000 (AF,BF,GF) = 44.00000 18.00000 265.67001

NDXM = 96 NDXS = 218



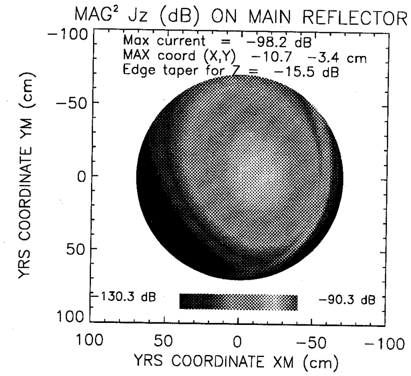
h3p0q35.spw mainoff_u10.dat 35. GHz

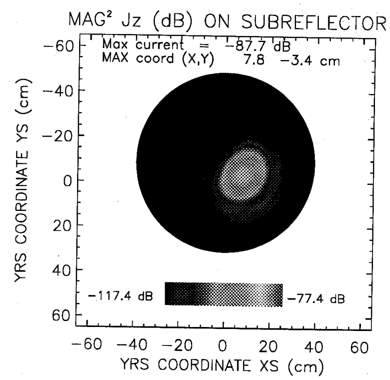
dadra.dat file39.dat

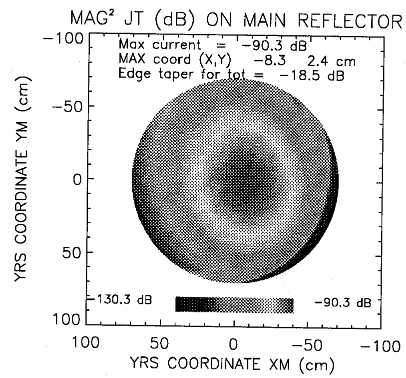
(XS,YS,ZS) = 0.00000 114.40212 0.00000 (XF,YF,ZF) = -7.20000 8.80000 7.00000

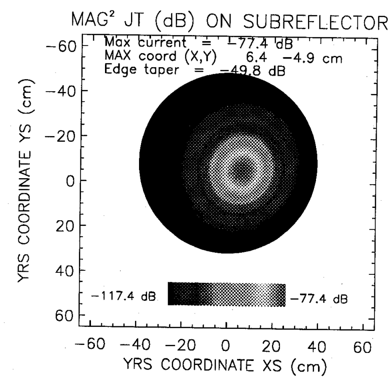
(AS,BS,GS) = 0.00000 -19.92000 0.00000 (AF,BF,GF) = 44.00000 18.00000 265.67001

NDXM = 96 NDXS = 218









STRUCTURAL THERMAL OPTICAL PERFORMANCE ANALYSIS (STOP)

Select parameters to describe optical performance:

- Pointing: Elevation and Azimuth
- Beam width: Full width half max. (FWHM)

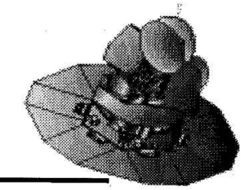
Determine the variations (degradation) in performance as each component (primary, secondary, and feed) is independently translated or rotated a unit displacement as a rigid body. This is called the sensitivity matrix.

Calculate expected displacements of the optical components.

- Primary mirror: TRS Spec max. allowable
- Secondary Mirror: TRS spec max. allowable
- Feed Horn: Calculated worst case estimate

Scale the sensitivity numbers obtained for a unit displacement according to the expected displacement and superpose values for all degrees of freedom to obtain the final performance.

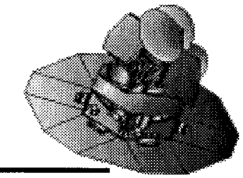
SENSITIVITY TO RIGID-BODY DISPLACEMENTS



Microwave Optics

Optical Components			Sensitivity of Perfromance to Independent Rigid Body Displacements								
	DOF	Unit Displacement (in. or deg.)	Elevation (deg) +/- 0.005	Azimuth (deg) +/- 0.011	Window_y +/- 0.005	Polarization (deg)	Gain (dBi) +/- 0.0005	FWHMx (deg) +/- 0.0005	FWHMy (deg) +/- 0.0005	FW15dBx (deg) +/- 0.0005	FW15dBy (deg) +/- 0.0005
Primary	Δ x (in)	0.015	0.000	0.021	0.21	0.008	0.003	0.000	0.000	0.000	0.000
	Δ y (in)	0.015	0.010	0.000	0.31	0.001	0.012	0.001	0.000	0.001	0.000
	Δ z (in)	0.015	0.010	0.000	0.29	0.001	0.005	0.000	0.000	0.000	0.000
	θ x (deg)	0.04	0.080	0.000	0.95	0.002	0.006	0.001	0.000	0.001	0.000
	θ y (deg)	0.04	0.000	0.035	1.09	0.030	0.004	0.000	0.000	0.000	0.001
	θ z (deg)	0.04	0.000	0.008	0.55	0.025	0.010	0.000	0.001	0.000	0.001
Secondary	Δ x (in)	0.015	0.000	0.021	1.02	0.041	0.012	0.000	0.000	0.001	0.001
	Δ y (in)	0.015	0.010	0.000	1.04	0.002	0.018	0.001	0.000	0.002	0.000
	Δ z (in)	0.015	0.020	0.000	0.28	0.005	0.008	0.000	0.000	0.000	0.001
	θ x (deg)	0.04	0.020	0.000	0.89	0.002	0.017	0.000	0.001	0.001	0.002
	θ y (deg)	0.04	0.000	0.000	1.00	0.010	0.004	0.000	0.000	0.001	0.001
	θ z (deg)	0.04	0.000	0.021	0.29	0.026	0.008	0.000	0.000	0.000	0.000
Feed Horn	Δ x (in)	0.015	0.000	0.011	0.23	0.030	0.003	0.000	0.000	0.000	0.000
	Δ y (in)	0.015	0.000	0.000	0.69	0.002	0.011	0.000	0.001	0.000	0.001
	Δ z (in)	0.015	0.010	0.000	0.30	0.004	0.005	0.000	0.000	0.000	0.000
	θ x (deg)	0.04	0.000	0.000	0.03	0.004	0.001	0.000	0.000	0.000	0.000
	θ y (deg)	0.04	0.000	0.000	0.03	0.039	0.000	0.000	0.000	0.000	0.000
	θ z (deg)	0.04	0.000	0.000	0.02	0.007	0.001	0.000	0.000	0.000	0.000
Perfromance Nominal Value ==>			20.069	-0.575	554.56	45.005	59.698	0.194	0.202	0.415	0.434

OPTICAL PERFORMANCE PREDICTION



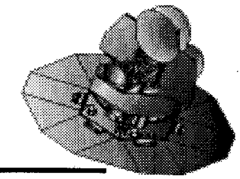
Worst Case Displacement Set

OPTICAL PARAMETERS	UNITS	NOMINAL VALUES	PERFORMANCE LOSS		
			ON GROUND	AT L2	BUDGET
POINTING - ELEVATION	(deg)	20.069	0.109 +/-0.104	0.104	0.5
POINTING - AZIMUTH	(deg)	0.575	0.137 +/-0.100	0.100	2
BEAMWIDTH - FWHM X	(deg)	0.194	0.006 +/-0.004	0.004	0.02
BEAMWIDTH - FWHM Y	(deg)	0.202	0.013 +/-0.004	0.004	0.02

Notes:

- Performance predictions are for W-Band.
- For pointing, performance loss represents a plus or minus deviation from the nominal value.
- For beam width, performance loss represents an increase from the nominal value.
- The budget values are for on orbit operation at L2.

STOP: Future Work

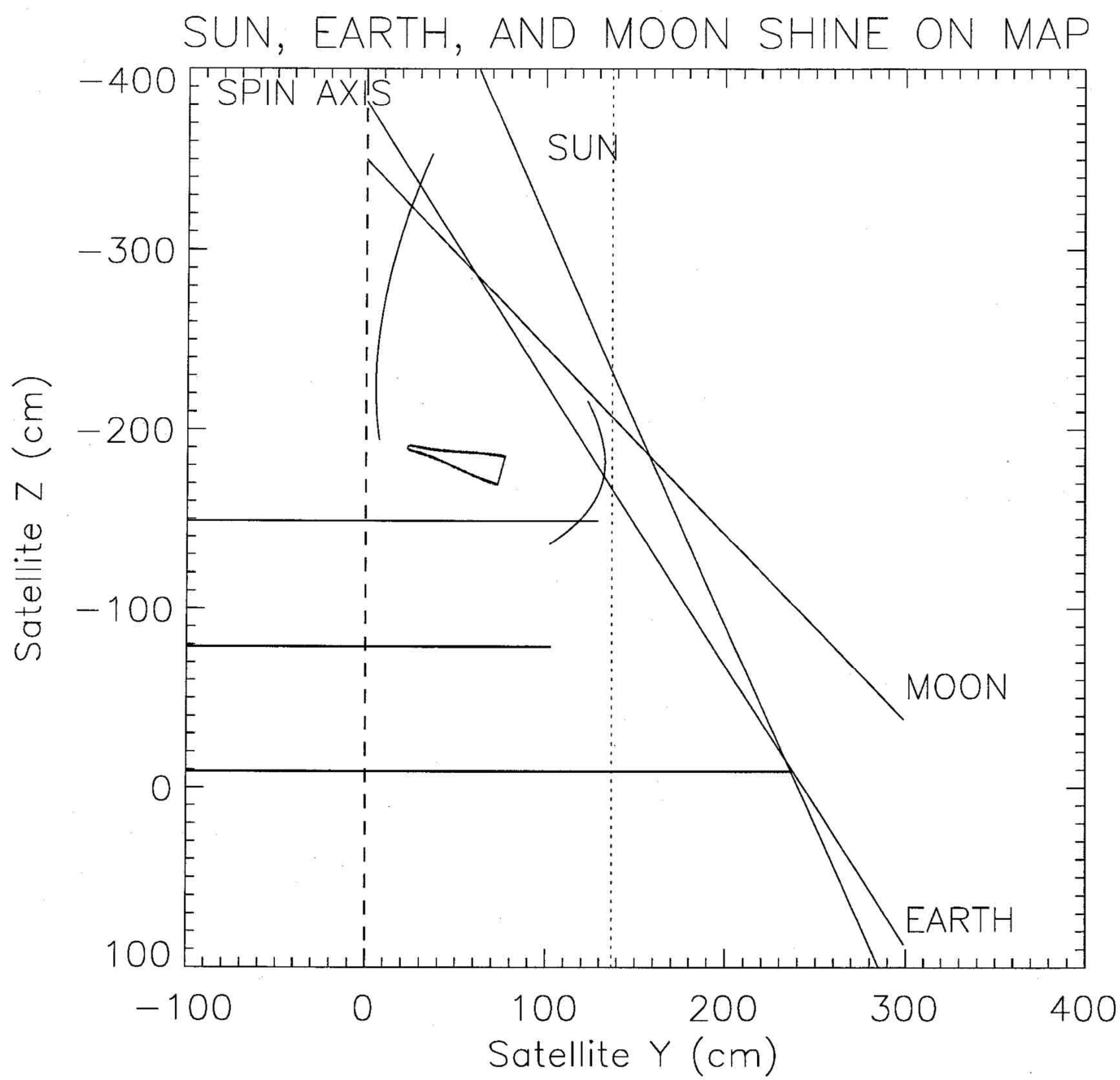


Displacement sets to be applied to the sensitivity matrix

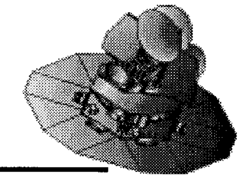
- Worst Case Displacement Set (Completed)
- On orbit - nominal case thermal predictions
- On orbit - warm case thermal predictions
- On orbit - cold case thermal predictions
- Temp gradient in x, y, and z
- Bulk ΔT

Displacement sets to be analyzed using the optic code YRS

- On orbit - nominal case thermal predictions
- Measured displacements from thermal tests


SUN, EARTH, AND MOON SHINE ON MAP
SPIN AXIS
SUN
MOON
EARTH
Satellite Z (cm)
Satellite Y (cm)
−400
−300
−200
−100
0
100
−100
0
100
200
300
400

COMPUTED SIGNALS FROM SUN, EARTH, & MOON



- GTD calls show dominant path is over solar shield over secondary and into feeds. Other paths have been investigated. In K-band we compute

	SUN	EARTH	MOON
T_A	1nk	2nk	1.2nk
SPEC	500nk	500nk	500nk

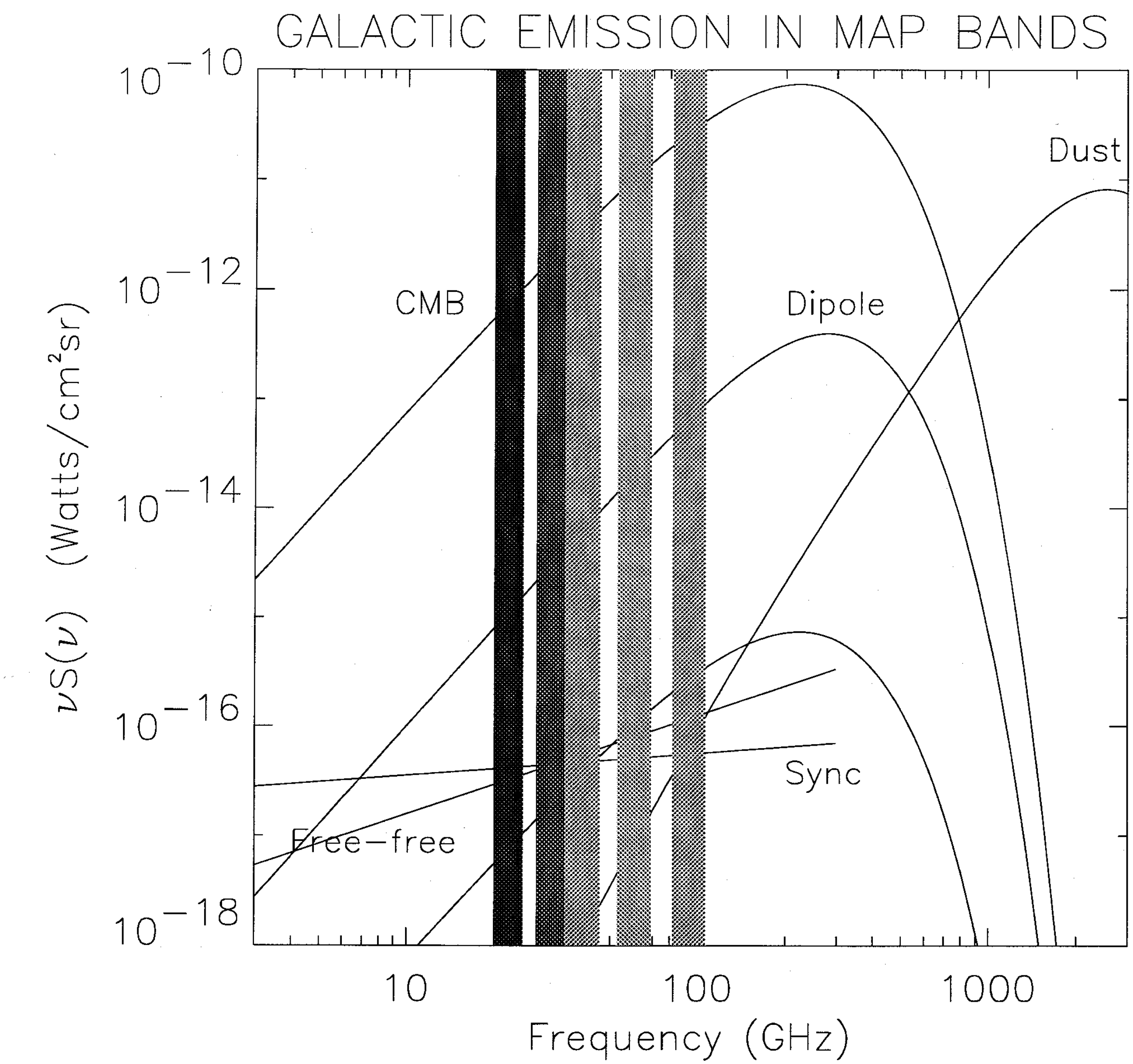
- Lunar emission not significant
- Earth shine on primary (10^{-2} w/m^2) will produce $\Delta T = 50\mu k$ (radiometric) on long time scales
- MLI over truss blocks radiation over side

COMPUTED SIGNAL FROM GALAXY

- Undesired galactic emission comes through nearlobes and far sidelobes
- Use Gary Hinshaw's galaxy model with T=300 *m*k at 22 GHz at center with 1° resolution Tgal ~ freq $^{-2}$
- Compute full sky map with YRS code (Hersey). Ignore all radiation within 5° of main lobe. Try multiple orientations of S/C
- Basic results agree with independent code by L. Page
- Goal Tgal < 4μk at b>20°

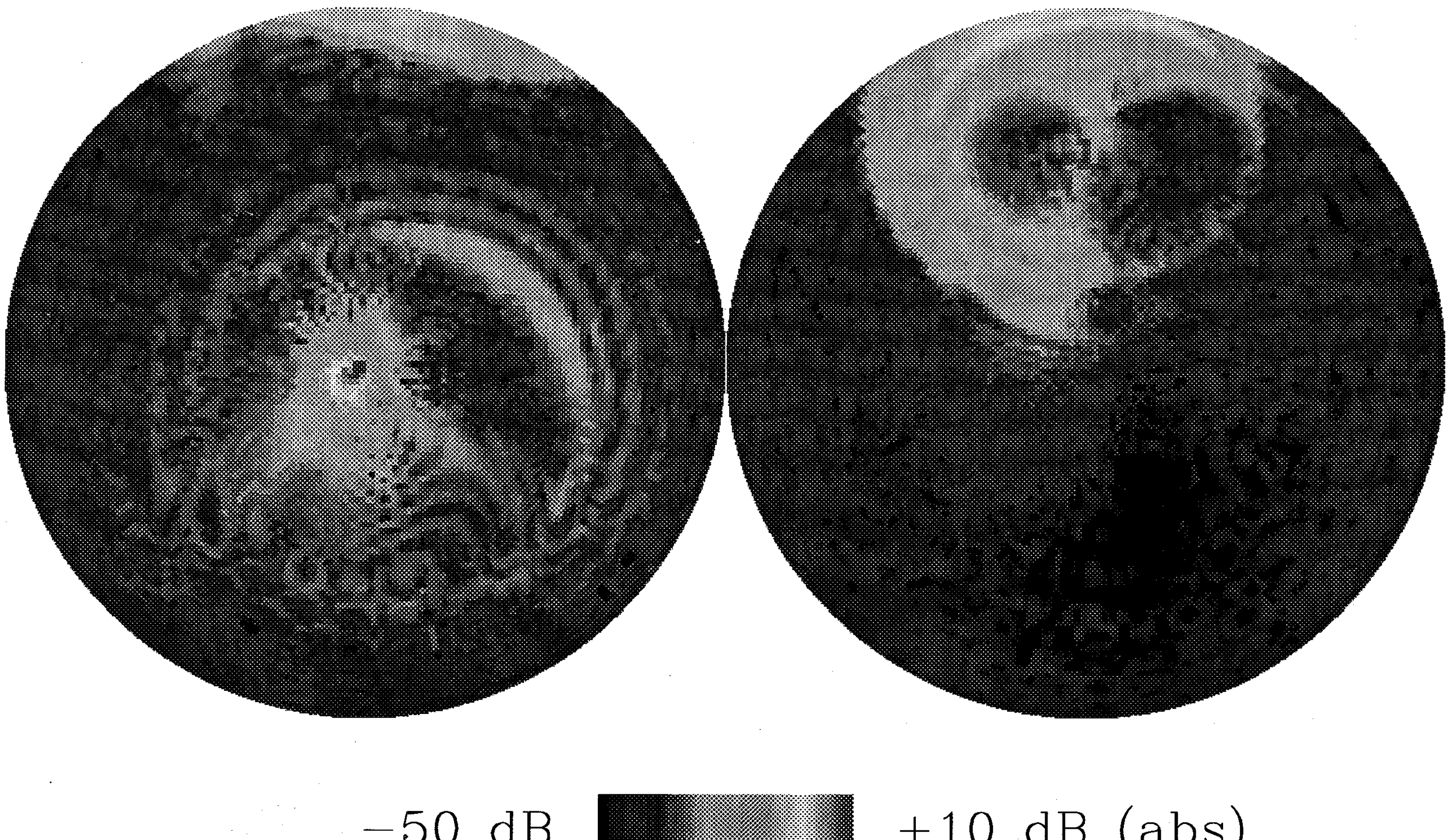
μK

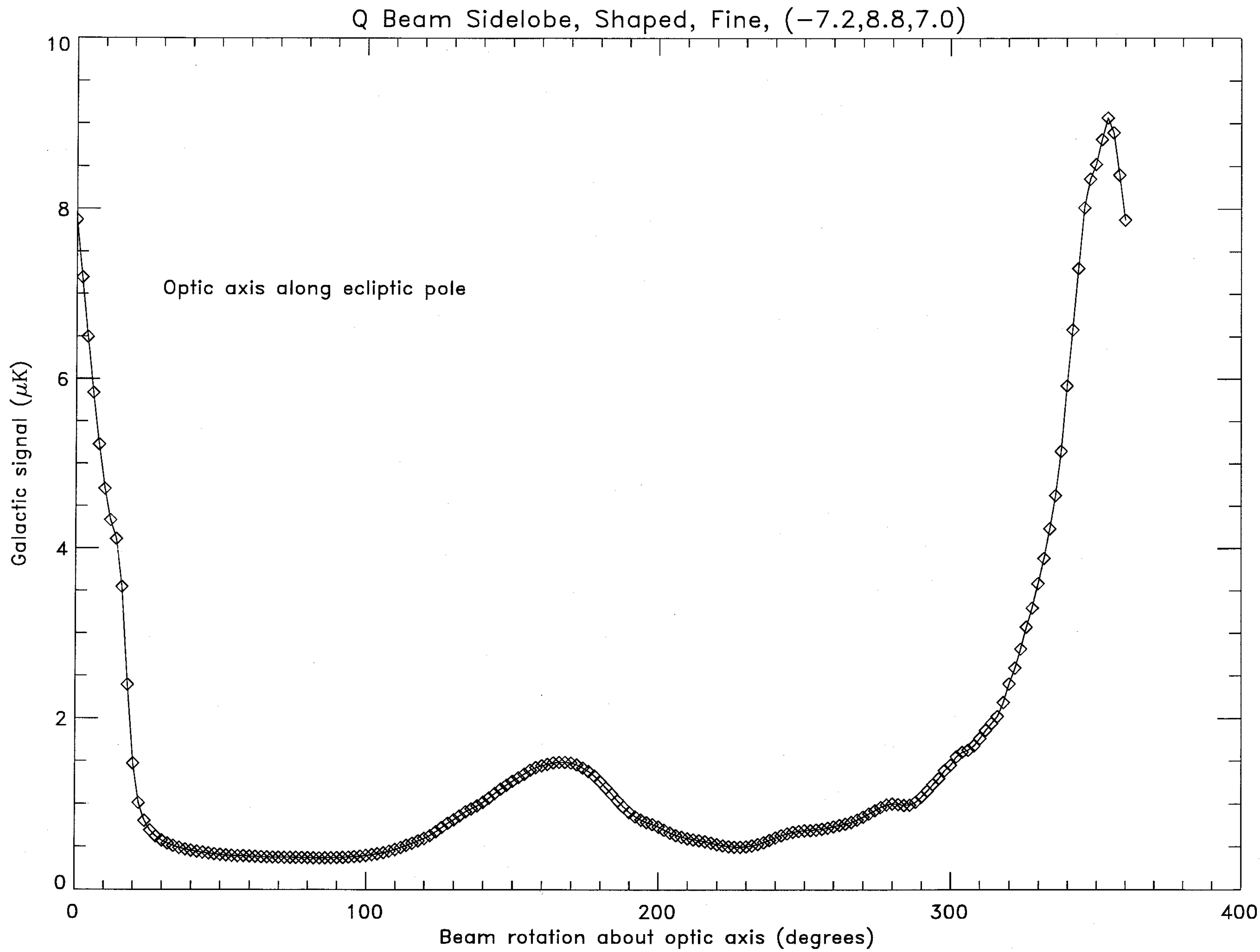
	K	Ka	Q (35 GHz)	V	W
MAX	80	...	9	1	4
MEDIAN	12	...	2	1	...
MIN	5	...	1	0	0



GALACTIC EMISSION IN MAP BANDS
10^{-10}
10^{-12}
10^{-14}
10^{-16}
10^{-18}
$\nu S(\nu)$ (Watts/cm²sr)
CMB
Dipole
Dust
Sync
Free−free
10
100
1000
Frequency (GHz)

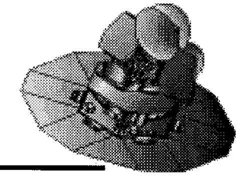
Q–band Beam Map, Shaped, Fine, (−7.2,8.8,7.0)



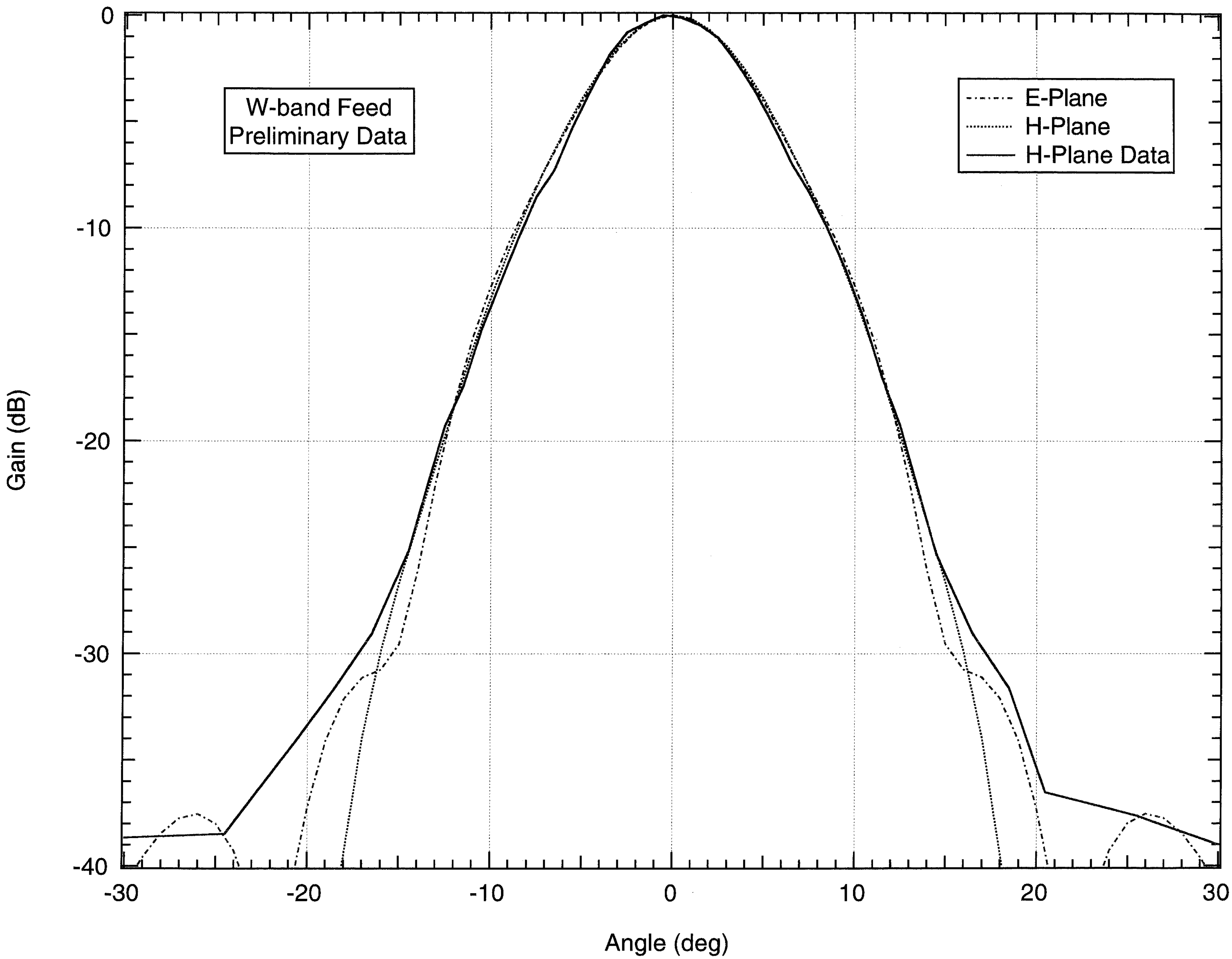


Q Beam Sidelobe, Shaped, Fine, (−7.2,8.8,7.0)
Optic axis along ecliptic pole
Galactic signal (μK)
Beam rotation about optic axis (degrees)
0
2
4
6
8
10
0
100
200
300
400

PLAN OF VERIFICATION OF MAIN BEAM AND SIDELOBES



- Main beam mapped at compact range by Ken Hersey (to -40dB)
- Map polarization at compact range
- Sidelobe measurement and check of main beam at roof range by M Limon. Specialized range design by T. Griffith and M. Limon to allow mapping over 2π sr will test one telescope that is indentical in form and function to flight unit. Mock ground screens made from Al honeycomb
- Map telescope to -90 dB (cannot be done in space) on roof range
- Test for glint paths on roof range
- Map from solar direction. Test GTD calls. Test solar heating on roof range
- Measure cross-pol and polarization response (cannot be done in space) at compact range and roof range
- Ultimately map main beam from space (Jupiter) with Jupiter and Cas-A.


W-band Feed
Preliminary Data
E-Plane
H-Plane
H-Plane Data
Gain (dB)
Angle (deg)
0
-10
-20
-30
-40
-30
-20
-10
0
10
20
30

SOURCES OF BEAM DEGRADATION (AFTER MANUFACTURING)

1 Contamination from thrusters, out-gassing etc. Model from Philip Chen (Code 984, GSFC)

	TOTAL PREDICTION FOR MISSION	MAX ALLOWABLE
WATER	0.5um	5um
HYDROCARBONS	1um	5um
AMMONIA	<0.1um	5um
ANILIN, IRON, HYDRAZINE	Trace	
		15um

Max set by two constraints

- Absorption
- Surface Roughness (dominates)

Max allowable for T<1μk

2 Dust on mirrors (e.g. carbon) ___

- Scattering of Earth/Moon shine
- Thermal emission ___

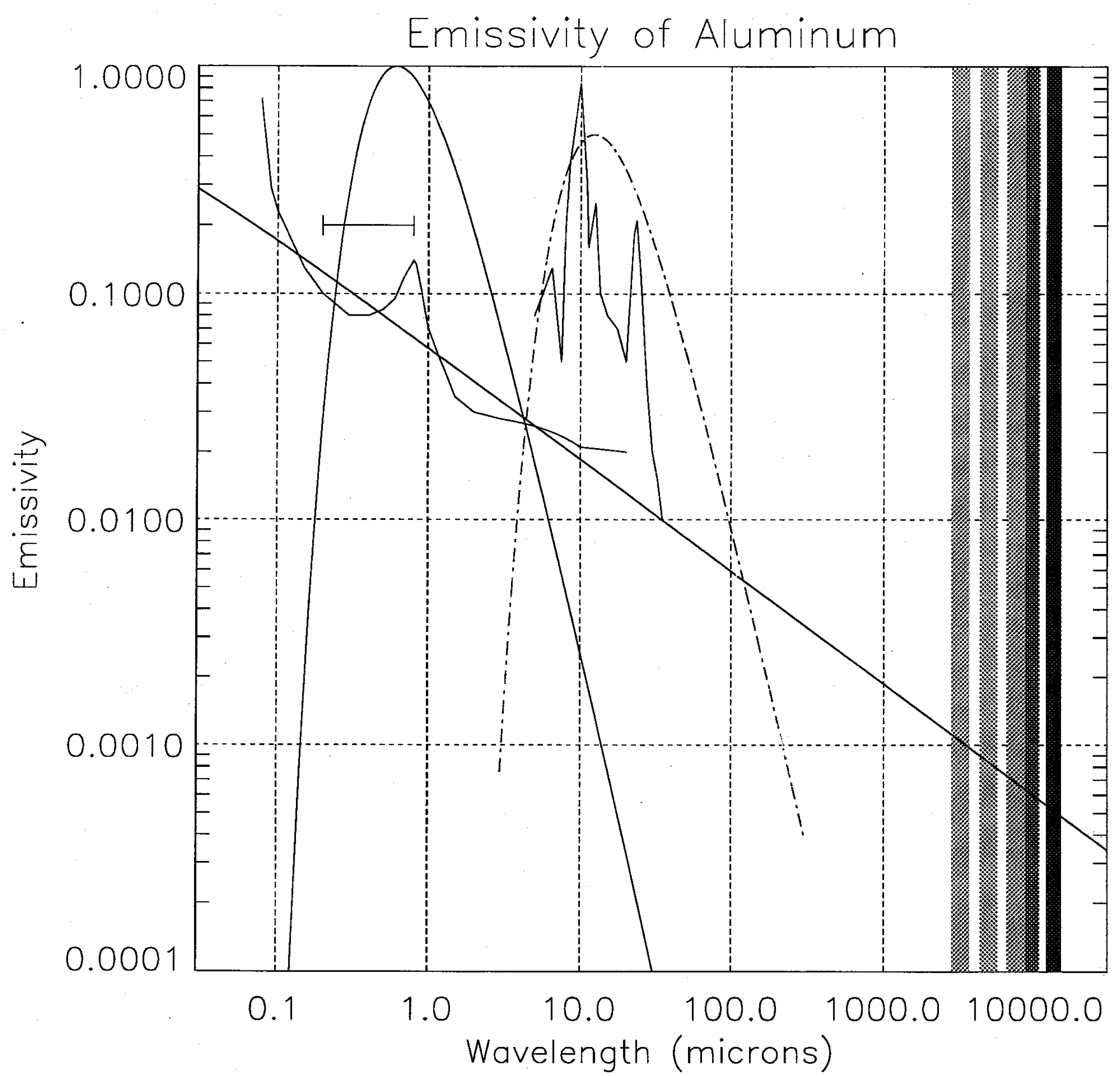
PROCUREMENT/MANUFACTURING PLAN - OMT'S

- OMT's made by Gamma - *f*
  - Have K, Q, W Bands
    - Meet Spec
    - Gamma-*f* has built space qualified components
  - Small redesign of flange needed
  - Minimal lightweighting needed
  - K_a & V ordered (prototypes)
  - Flight units in Q and W bands ordered
  - Loss estimated but not yet measured
- Backup designs in W-band (Millitech) and Q-band (Wollack). Will stop work on these after backup prototypes
- Verify with network analyzer and cold tests (for loss)

PROCUREMENT/MANUFACTURING PLAN - FEEDS

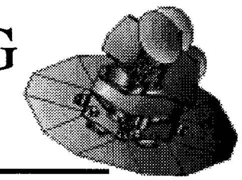
- Flight feeds manufacturing at Princeton by Glenn Atkinson and Michele Limon
- Will inspect and test
- Make K and W bands first (these bound the RF design)
- Will measure loss with cold loads

	K	Ka	Q	V	W
Mass Models	2	2	4	4	8
Flight Units	3	3	5	5	9
GSE	2	2	2	2	2



Emissivity of Aluminum
1.0000
0.1000
0.0100
0.0010
0.0001
Emissivity
0.1
1.0
10.0
100.0
1000.0
10000.0
Wavelength (microns)

PROCUREMENT MANUFACTURING PLAN - RELECTORS



- *PCI selected as vendor. Has built ~12 reflectors of similar dimensions for satellites in past
- Photogrammetry test at 130 K on PCI sample indicates that reflectors will work on orbit at 40K
- PCI has shape of optics in computer program
- Full spec on optics worked out with vendor
  - Essentially place optics within a "Fuzz Zone" of ± 0.015" around design position
- REU delivered to GSFC/Princeton Nov '97

*PCI - Programmed Composites Inc.

VERIFICATION OF REFLECTOR MANUFACTURING

Microwave Optics

YRS CODE

↓

LP CODE FOR TRANSFORMATION

↓

PCI GENERATES TOOL COODINATES

↓

COORD & TRANS TO YRS FOR VERIFICATION

↓

PCI BUILD

→

TEST UNIT (REU) TO GSFC

NOV 25 '97

↓

PHOTOGRAMMETRY AT GSFC

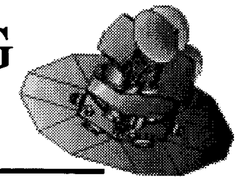
↓

W-BAND BEAM MAP AT COMPACT RANGE TO WORK BUGS OUT

↓

REU TO PRINCETON FOR MAPPING

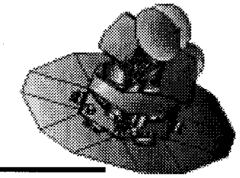
PROCUREMENT MANUFACTURING PLAN - SURFACE



Microwave Optics

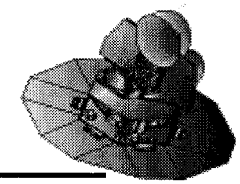
- PCI will subcontract to SOC to do surface
  - Surface Spec:
    - $\varepsilon<0.0011$ (or 0.1% bulk A1) @ 90GHz and 300K
    - RMS of 0.3μm to diffuse polar radiation
    - $\mathbf{S_i0_x}$ coating 10μm to emit in IR
  - From test samples we know that PCI reflectors satisfy all figure/RMS criteria on length scale >1mm

VERIFICATION OF SURFACE PROPERTIES



- Primary verification through measurements on coupons
  - Use existing sample from PCI (not coated by SOC)
  - Get second sample to test within 1 month, before CDR
  - Test coupons from final coating
  - <u>Emmisivity</u>
    - FTS at UBC to compare surface to bulk A1
    - 90GHz radiometer at Princeton to compare to bulk A1
    - Preliminary results show that for a surface roughened with 180 grit, R>0.999. This roughness far exceed that expected for MAP (Dorwart)
  - <u>Surface Roughness</u>
    - Measured at GSFC and SOC
      - alpha/epsilon
    - Measured at SOC and GSFC
  - <u>Surface Charging</u>
    - Measured at GSFC on test samples

VERIFICATION OF REFLECTOR SURFACE



- Use 90 GHz radiometer and roof range
- Heat secondary and primary by $\Delta T = 50^{\circ}C$ to produce a $50mk$ signal

INTRODUCTION/TOPICS

Prototype status — Assembly procedure — Verification plan

Frequency coverage	Sensitivity	Systematic errors (stability)
[HEMT amplifiers]	RF bandwidth system noise [integration time]	radiometer configuration [scanning rate] [stable thermal/electrical interfaces]

ASSEMBLY PROCEDURE - KEY ITEMS

Component characterization

phase switches	insertion phase, loss balance
amplifiers	complex gain
waveguides	insertion phase, loss dimensions, VSWR
detectors	VSWR, responsivity vs. frequency
filters	passband flatness
hybrid tees	insertion loss, VSWR (colinear arms)
orthomode transducers	VSWR

Radiometer assembly

- 1st Assembly - hybrid tee to hybrid tee
  - complex gain at both 300K and 95K to determine amplifier bias points and shim thickness
- 2nd Assembly - hybrid tee to hybrid tee
  - install shim and characterize at both 300K and 95K
  - record complex gain of each leg
  - record amplifier operating currents
  - search for parasitic oscillations
- 3rd Assembly - hybrid tee to detector
  - operate as full radiometer from input hybrid tee to line driver output including flight phase switch driver

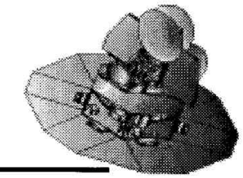
Combine two radiometers into a differencing assembly

- 4th Assembly - orthomode transducer to line driver output

VERIFICATION OVERVIEW

- Entire radiometer operated as a unit in cryogenic test chamber in very close to flight environment
- Various levels of testing during assembly, culminating in end-to-end tests from orthomode transducers to line driver outputs
- Flight line driver and phase switch drivers used during final verification
- Power supply circuits used during ground tests are clones of flight design
- Radiometer will operate at both cryogenic and room temperatures
- Final characterization will occur at both cryogenic and room temperatures
- During integration differencing assembly performance is compared to final room temperature Princeton characterizations to insure no damage has been done to radiometer

TEST CHAMBERS



Quantity 3

Operate differencing assembly in flight like conditions

Warm components	0 - 50°C
Cold components	85 - 100 K
Cryogenic loads	about 25 K

Thermal vacuum environment

Allows operation of each radiometer on a differencing assembly from orthomode transducer input to line driver output including phase switch driver circuit board with selected resistors

FINAL VERIFICATION

At final radiometer level thorough characterization at both room temperature and nominal operating temperature (20˚C, 95K) for the following:

- responsivity
- noise level
- power spectrum
- offset
- detector biases
- power dissipation

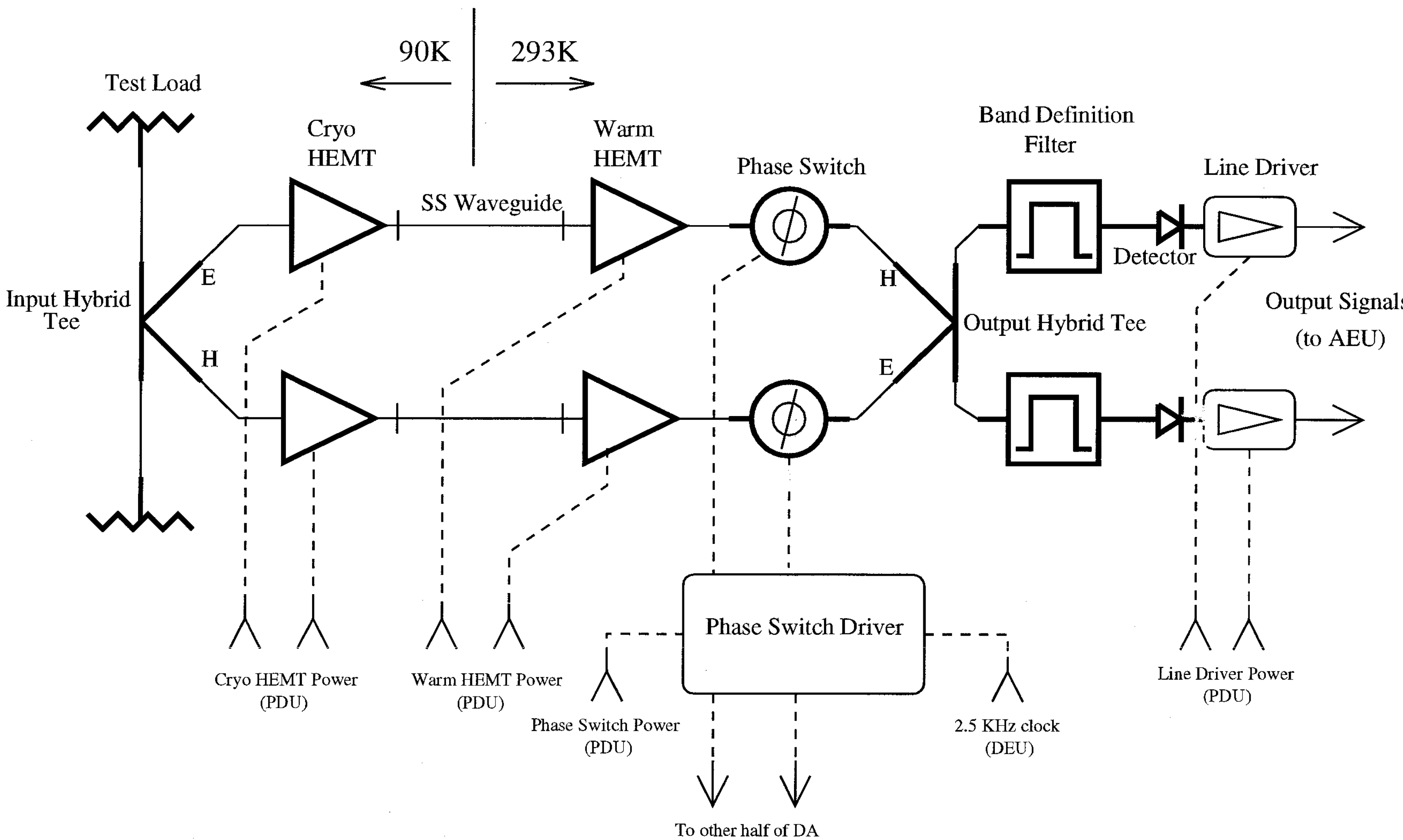
Some key items also characterized at qual. temp limis of warm end (0-50˚C)

At final Differencing assembly level, thorough chracterization at both room temperature and nominal operating temperature (20˚C, 95K) fo the following:

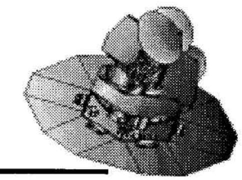
- responsivity
- noise level
- power spectrum
- offset
- detector biases
- power dissipation
- bandpasses

Some key items also chracterized at qual. temp. limits of the cold end (85 - 110K)

Q-band Prototype Radiometer



Q-BAND PROTOTYPE CONFIGURATION

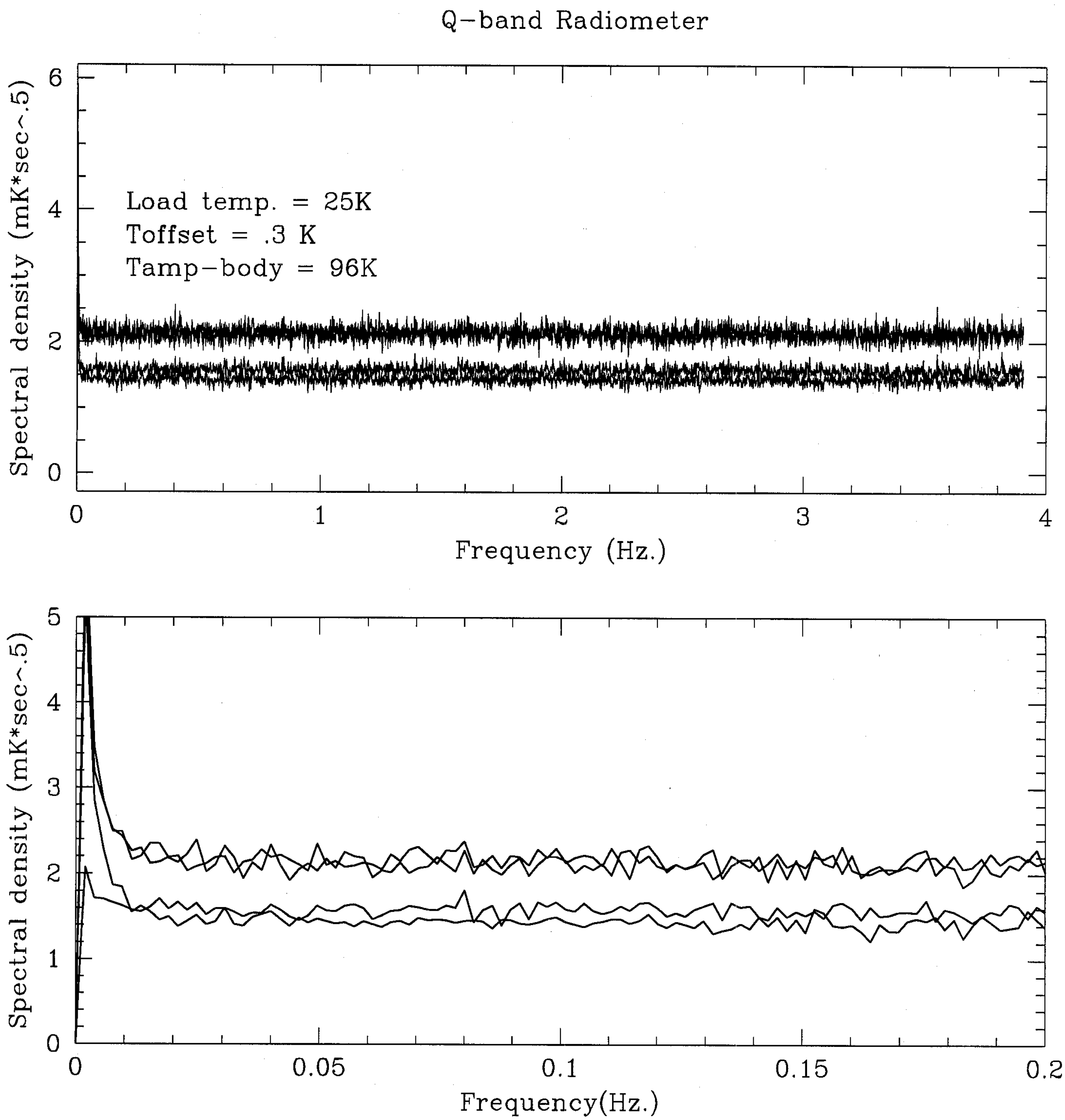


- All InP amplifiers with MAP wafer (passivated) devices
- Gain flatness not MAP final design
- E/H radiometer configuration- very close to flight-like
- Bandpass filters used - flight-like prototypes
- Detectors - not final balanced design
- Cryogenic loads on hybrid tee inputs

Q-BAND PROTOTYPE PERFORMANCE

	Prototype (measured)	Projected for flight model (based on measured data)	Proposal
Tsys (lab)	82K		
(flight)	61K	53K	59K
BWeff	7.5GHz	7.5GHz	8GHz
Sensitivity (mk*sec^.5)			
(lab)	2.05		
(expected)	1.89		
(flight)	1.41	1.22	1.32

Lab physical temperature = 103K   Lab load temperatuer = 24K



Q-band Radiometer
Load temp. = 25K
Toffset = .3 K
Tamp-body = 96K
Spectral density (mK*sec^.5)
Frequency (Hz.)
Spectral density (mK*sec^.5)
Frequency(Hz.)

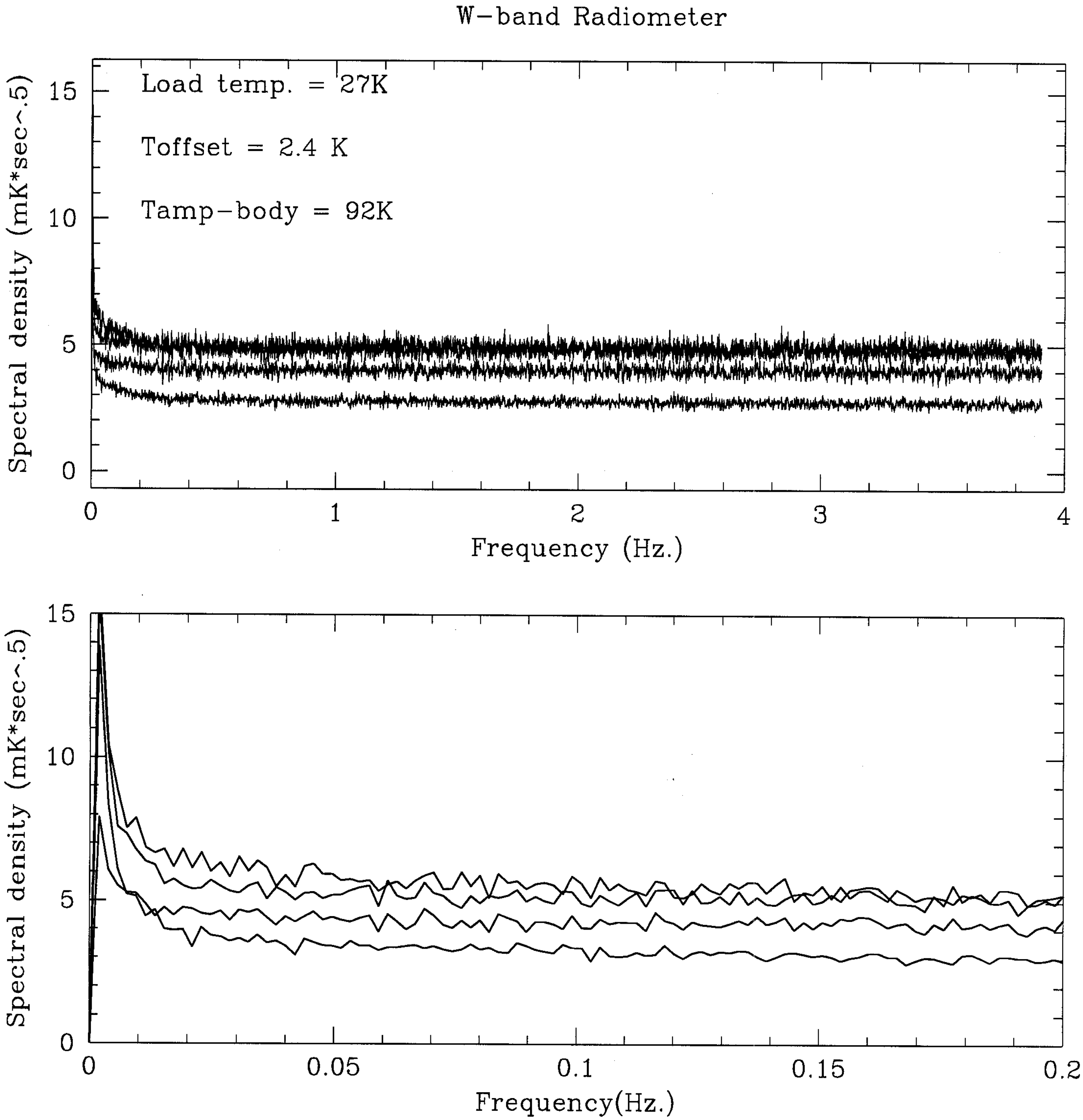
W-BAND PROTOTYPE CONFIGURATION

- All InP amplifiers with NRAO wafer (unpassivated) devices
- Gain flatness not MAP final design
- 3 amplifiers per side - excess gain
- 3 dB pads in front of detectors to simulate loss of filters
- Balanced detectors - flight-like prototypes
- Symmetric configuration - to simplify prototype layout
- Using flight-like line driver prototypes

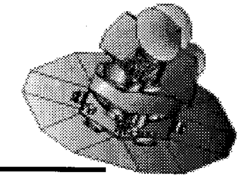
W-BAND PROTOTYPE PERFORMANCE

	Prototype (measured)	Projected for flight model (based on measured data)	Proposal
Tsys (lab)	171K		
(flight)	149K	130K	145K
BWeff	7.5GHz	16GHz	19GHz
Sensitivity (mk*sec^.5)			
(lab)	3.9		
(expected)	3.9		
(flight)	3.4	2.06	2.1

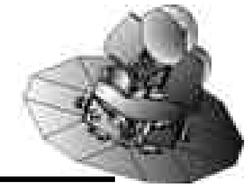
Lab physical temperature = 96K   Lab load temperatuer = 24K


W−band Radiometer
Load temp. = 27K
Toffset = 2.4 K
Tamp−body = 92K
Spectral density (mK*sec^.5)
0
5
10
15
0
1
2
3
4
Frequency (Hz.)
Spectral density (mK*sec^.5)
0
5
10
15
0
0.05
0.1
0.15
0.2
Frequency(Hz.)

ASSEMBLY PROCEDURE OVERVIEW



- Based on prototype experience
- Characterize key prameters of components based on models & experience
- Match components analytically
- 3 major assembly steps per radiometer
- 1 final step to integrate both radiometers into a differencing assembly
- 3 differencing assemblies simultaneously in assembly
- Verification of key prameters occurs continuously during each assembly step



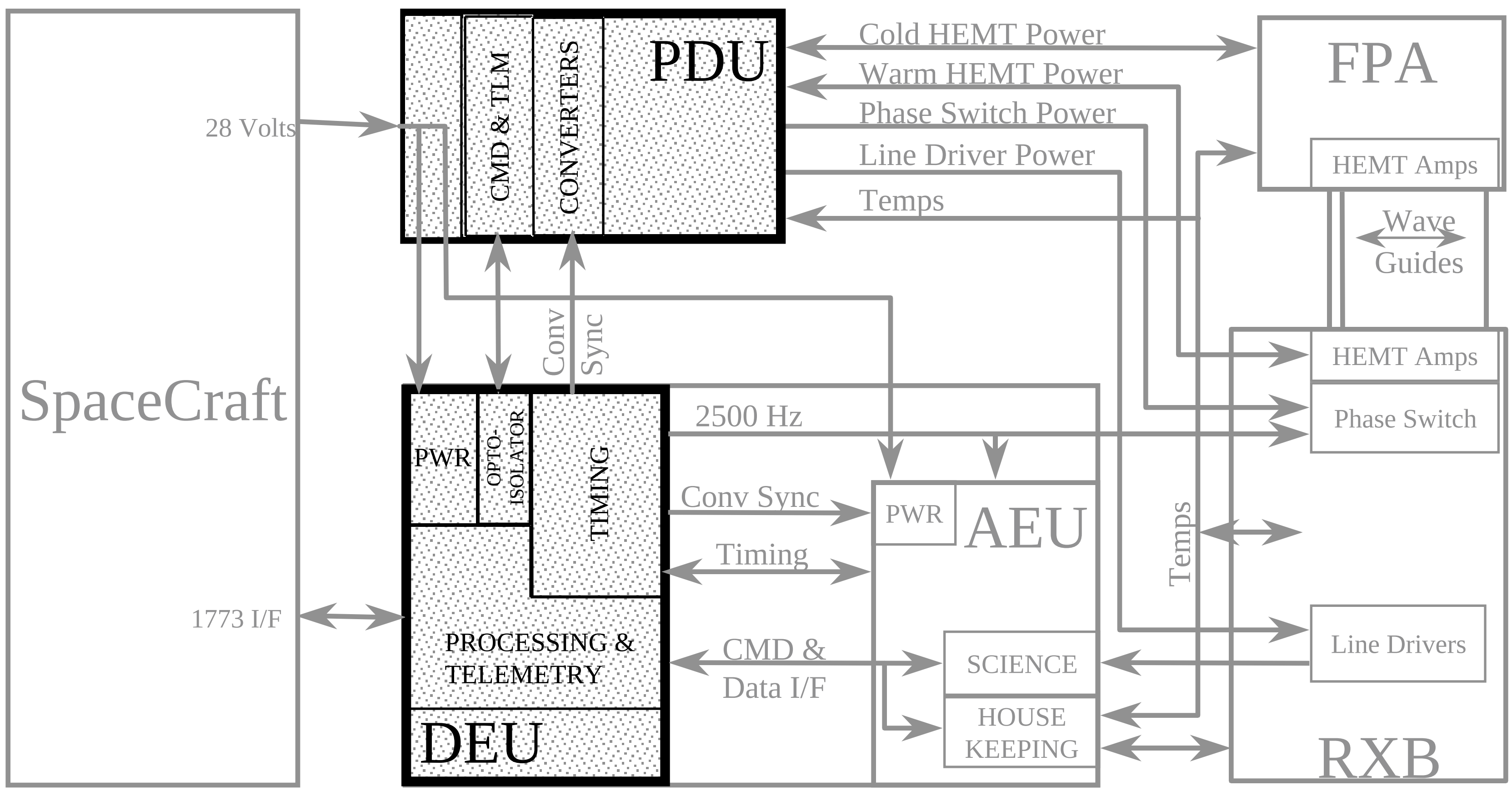
INSTRUMENT ELECTRONICS

James N. Caldwell -- Instrument Electronics Product Lead

David Bergman -- AEU Lead Engineer
Renan Borelli -- DEU Lead Engineer
Carlos Trujillo -- Instrument Flight Software
Carl Kellenbenz -- PDU Lead Engineer
Dale Brigham -- PDU Hemt Regulator Design
Diane Yun -- PDU Converter Design
Namrita Kapur -- PDU Converter Design
Rob Gallagher -- Instrument Test Engineer
Manuel Florez -- PDU Bench Test Equipment

ELECTRONICS BLOCK DIAGRAM

Instrument Electronics



PDU Requirements

- PDU Electrical Interface Requirements
  - Power Bus Range
    - 30 +5/-9 Volts nominal
  - Power Bus Variation
    - 30 +/- 0.5 p-p Volts at Spin rate
  - Supply 30 Volt Power to AEUand DEU assemblies
    - Plug-in EMI enclosed Power Cards
  - Converter Sync
    - PDU, DEU, AEU Synchronized to 100 KHz

PDU Requirements

- Radiation Tolerance
  - Operate within spec for a total dose of 27 KRads (assuming 100 mil Al shielding, and an RDM of 2)
- Temperature Range
  - Operate within spec at any operating point from 0 to 40 C
- Temperature Variation
  - Maintain spin synchronous output power within specs when PDU box temperature variations at the spin rate are less than 10 mK

PDU Salient Requirements

Instrument Electronics - PDU

Function	Performance Requirements	Comments	Verification
HEMT Amplifier Power	All HEMT drain and gate voltages, both cold and warm, shall be regulated at the HEMT amplifier connector by remote-sensing feedback to the regulators.	Individual drain and gate regulator circuits are designed to meet the requirements for each of 40 cold amplifiers and 40 warm amplifiers	Design
	Provide fixed drain voltages settable 1.0 to 1.5v with ~70 mv resolution (8 steps), 35mA max.	Voltage settings stored in EEPROM on PDU Housekeeping board	Test
	Provide fixed gate voltages settable 0 to -0.5v with ~35 mv resolution (16 steps), 1.0 mA max.	Voltage settings stored in EEPROM on PDU Housekeeping board	Test
	Provide separate gate voltages commandable0 to -0.5 volt with ~35 mv resolution (16 steps), 1.0 mA max.		Test
	Broadband noise <100 nV/rHz @2.5KHz+/-50Hz and harmonics to 50KHz; drain: <23 uV/rHz 1 Hz to 50 Hz; <23/f^0.45 uV/rHz 0.3 mHz to 1 Hz [= 885 uV/rHz @0.3mHz]; gate: <20 uV/rHz 1 Hz to 50 Hz; <20/f^0.45 uV/rHz 0.3 mHz to 1 Hz [= 770 uV/rHz @0.3mHz]	Precession period = 1 hour (f_prec = ~0.3 mHz)	Test
	Spin-sync variations: drain: < 500 nV rms. at f_spin; for first 4 harmonics, 500*n^0.5 nV rms. (n = harmonic number) [<870 nV @ 3*f_spin] gate: < 400 nV rms. at f_spin; for first 4 harmonics, 400*n^0.5 nV rms. (n = harmonic number)	f_spin = Spin frequency = 7.57 mHz (132 sec period) [based on 0.454 rpm]	Test
	Drift: drain <10 mV, gate <5mv over mission lifetime, including operational temperature variations over 0 to 40C		Analysis
	Note: FPA and RXB HEMT Regulator Turn-on transient and overshoot shall b < 2.0v max. between Drain and Gate, and < -1.0v max. between Gate and Source, under any conditions.		Test
LED Power			
	Provide individual regulated current for LEDs on each FPA (cold) amplifier: mA +/-0.1 mA	LEDs will be operated in saturation to minimize light variations.	Test
	Drift <10% over mission lifetime		Analysis

PDU Salient Requirements

Instrument Electronics - PDU

Function	Performance Requirements	Comments	Verification
DA Phase Switch Power	Provide regulated power for phase switch driver circuits +9v +/-0.1v @ 990 mA max.; -9v +/-0.1v @ 990 mA max.	10 driver circuits total, one for each DA	Test
	Regulation +/-1%, line and load		Test
	Ripple 50mv; Noise 20mv common mode		Test
DA Line Driver Power	Provide regulated power for line driver amplifiers +6.25v +0.1/-0.0v @ 320 mA; -6.25v +0.1/-0.0v @ 320 mA	Uses linear regulators	Test
	Regulation +/-0.1%, line and load		Test
	Ripple 25mv, Noise 20mv common mode		Test
Telemetry	Provide digitized telemetry outputs using a 12-bit A/D: 40 FPA Drain Curren 40 RXB Drain Currents, all internal converter output voltages, and temperatur from the three converters.	All readings shall be taken at least 4 times per spin period readout	Design and Test

DEU Requirements

- DEU Requirements
  - Provide Coherent Timing and Control Signals
    - AEU
      - 1 MHz Clock (Voltage to Freq Converter Science and HK)
      - 25.6 mSec Tick
      - 2.5 KHz Demodulation Clock
      - Blanking Pulse (5 Khz)
      - 100 KHz Power Sync Clock
    - PDU
      - 100 KHz Power Sync Clock
    - DEU
      - 100 KHz Power Sync Clock
    - RXB
      - 2.5 KHz Phase Switch Clock

DEU Requirements

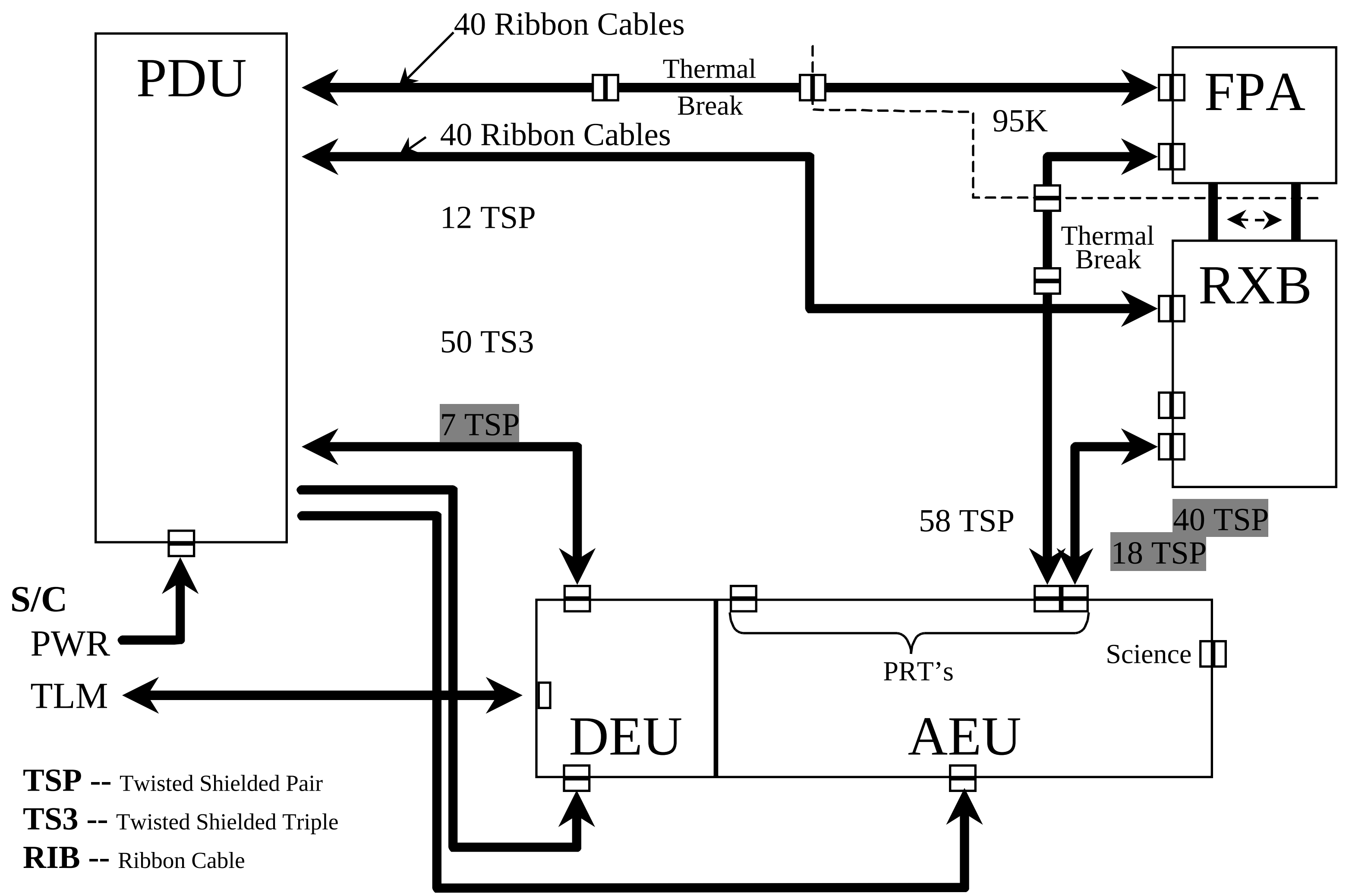
- Collect Science Data
  - 40 Channels of sky data every 25.6 mSec
- Collect Science-Housekeeping data From AEU
  - Collect 40 Channels of detector RF bias every 23.04 seconds
  - Collect up to 64 PRT mux channels every 23.04 seconds
- Collect Housekeeping Data from DEU, AEU & PDU
- Receive Commands and Transmit Telemetry to S/C using 1773 bus
- Maintain 27 month mission lifetime
- Withstand 27 KRad Total Dose
  (assuming 100 mil Al, RDM of 2)

Harness Requirements

- Harness Requirements and Responsibilities
  - Route power to FPA HEMT Amplifiers through the thermal break Area
    - Manufacturing special Ribbon Cable
    - Coordinate with thermal systems to maintain cold temperature at FPA
  - Route power to RXB HEMT Amplifiers
    - Manufacturing special Ribbon Cable
  - Terminate "Loose Ends" from RXB (Line Drivers, Phase Switch etc...)
    - Install each difference assembly wiring into bulkhead connectors when received
  - Wiring of all Heaters and PRT's as required
    - Attach and Connect Meeting Electrical and Thermal Specifications
  - Meet EMI/EMC requirements
    - Verification by Test

Harness Block Diagram

Instrument Electronics - Harness



TSP -- Twisted Shielded Pair
TS3 -- Twisted Shielded Triple
RIB -- Ribbon Cable

System Drivers

- Unique Challenges
  - 500 nV RMS Spin Synchronous Sensitivity
  - Isolated Composite Structure
    - Lack of intrinsic low impedance ground reference
  - Common Multiple Ground Paths
    - Characteristic of the instrument design
  - Stable Electrical and Magnetic Environment
    - Provide constant environment at the spin rate and modulation rate

System Approach

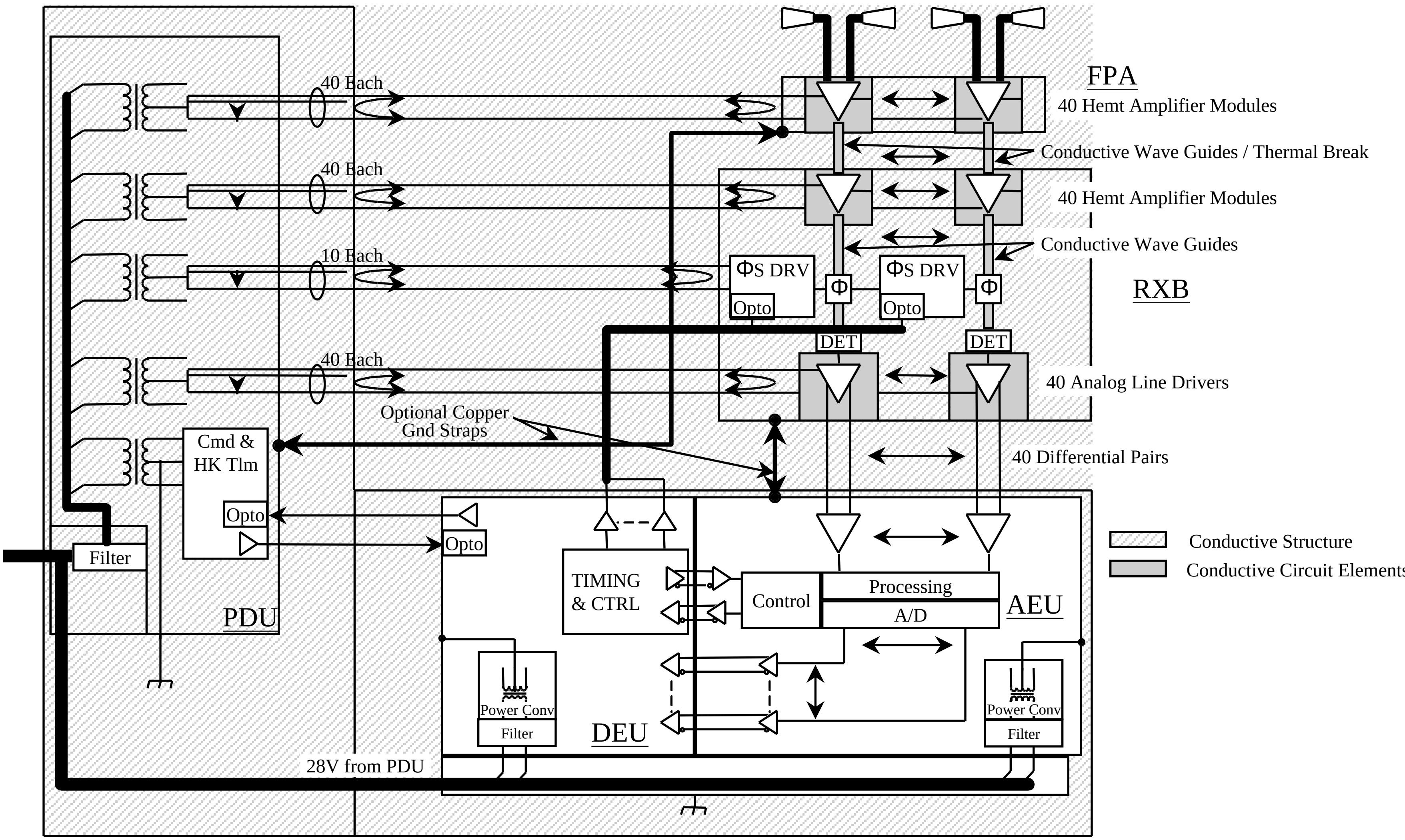
- Approach
  - Noise Control Plan
    - Minimize Load Variations -- 10 W P-P
    - Minimize Bus Voltage Variations -- 0.5 V P-P
    - Minimize S/C Common Mode Currents
      - 100 mV Requirement for Common Mode Noise for Components
      - 10 Mohm Isolation of Primary-Secondary Impedance
    - Minimize Impedance Between Subsystems
      - Use of Ground Plane on Composite Structure (2.5 mOhm)
    - Minimize Electrical Secondary Noise Between Subsystems
      - Fiber-optic 1773 Data Bus
    - Analysis and Modeling where appropriate
    - Special Tests -- i.e. Magnetic interaction effects of converters
  - Expert panel to Address Detailed System Grounding and Noise

Solutions

- Example of Solution to a Challenge
  - Grounding
    - Major problem -- 2500 Hz currents (See Diagram)
    - Solution
      - Analysis with computer-aided design tools (p-spice, etc.)
      - Expert Team Consultation and Discussion
      - Use of Common Mode Chokes in Phase Switch Driver
        - Resulted in 95% Reduction of Unwanted Currents in Each Circuit Branch

Grounding Diagram

Instrument Electronics - Systems



Timing & Control

- All Signals Coherent and derived from a single oscillator
- All Instrument Electronics Power Converters Synched
- DEU Provides all control signals for the operation of the AEU Electronics
- Housekeeping data is automatically tracked on scale by an offset ranging algorithm
- Commands are received in the DEU and distributed to the destinations.

Software Data Processing

- Software collects the science data every 25.6 mSec and accumulates the data in bins commensurate with the bandwidth of the radiometer being sampled.
- All data is time tagged or can be traced in time to a resolution of 1 millisecond.
- Data is packetized and transmitted to the spacecraft via the telemetry collection schedule. (1.536 Sec per packet)
- Science Data is compressed in the Mongoose V with a lossless data compression scheme developed at GSFC

Development Plan

Instrument Electronics

Hardware Development

BB Development

Critical Circuits

LNVU's

Testing:
- Bench Testing
- Differencing Assembly Testing at Princeton

PFU Design and Development

Environmental & Qualification Testing

Delivery

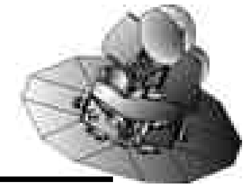
Reviews:
- Peer Design Reviews
- Project Level Reviews
- Pre-Fabrication Reviews
- Pre-Environmental Reviews

Design Approach

- Hardware designs are done and CAE simulations are employed in designs where feasible. Breadboards are developed and results verified.
- Critical and Sensitive circuits are also being fabricated and tested as non-flight “Low Noise Verification Units” or ETU’s
  - PDU Hemt Regulator
  - AEU Science processor
  - DEU Processor ETU
- Breadboard and LNVU integrated tests with the Differencing Assemblies at Princeton are a big part of the design progression.
- All instrument electronics boxes are being designed and built as Protoflight units.

Testing

- All units -- Breadboards and LNVU's are tested before the flight units for interface compatibility and functionality
- All units are thermal cycled at the bench level to verify the design parameters and operation
- All units undergo EMC common mode qualification at the box level
- All units undergo vibration, thermal vacuum and EMI/EMC tests (conducted and radiated susceptibility), to verify operation to spec over all required ranges



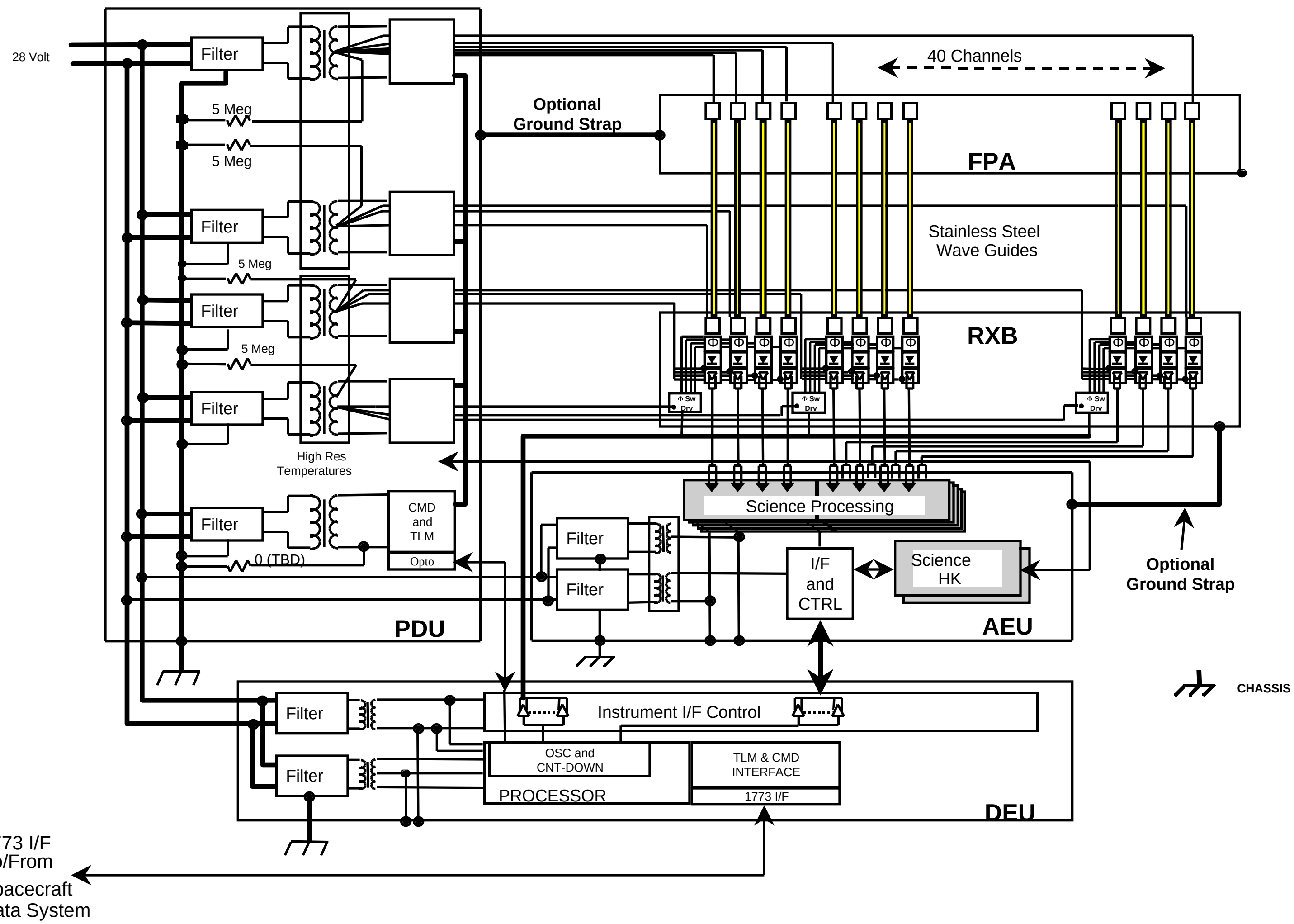
Status

- All Electronics Units have completed testing, have passed Environmental testing and are being integrated into the instrument test harness.
- Testing and verification of the software on the hardware is complete.
- The compression software has been coded and tested as a stand-alone program. Benchmarking on a mongoose s/w development board has been done.
- The Harness drawings are complete. The Hemt and PRT Thermal break harness is in fabrication and layout and fabrication of the instrument harness is underway.

Backup Material

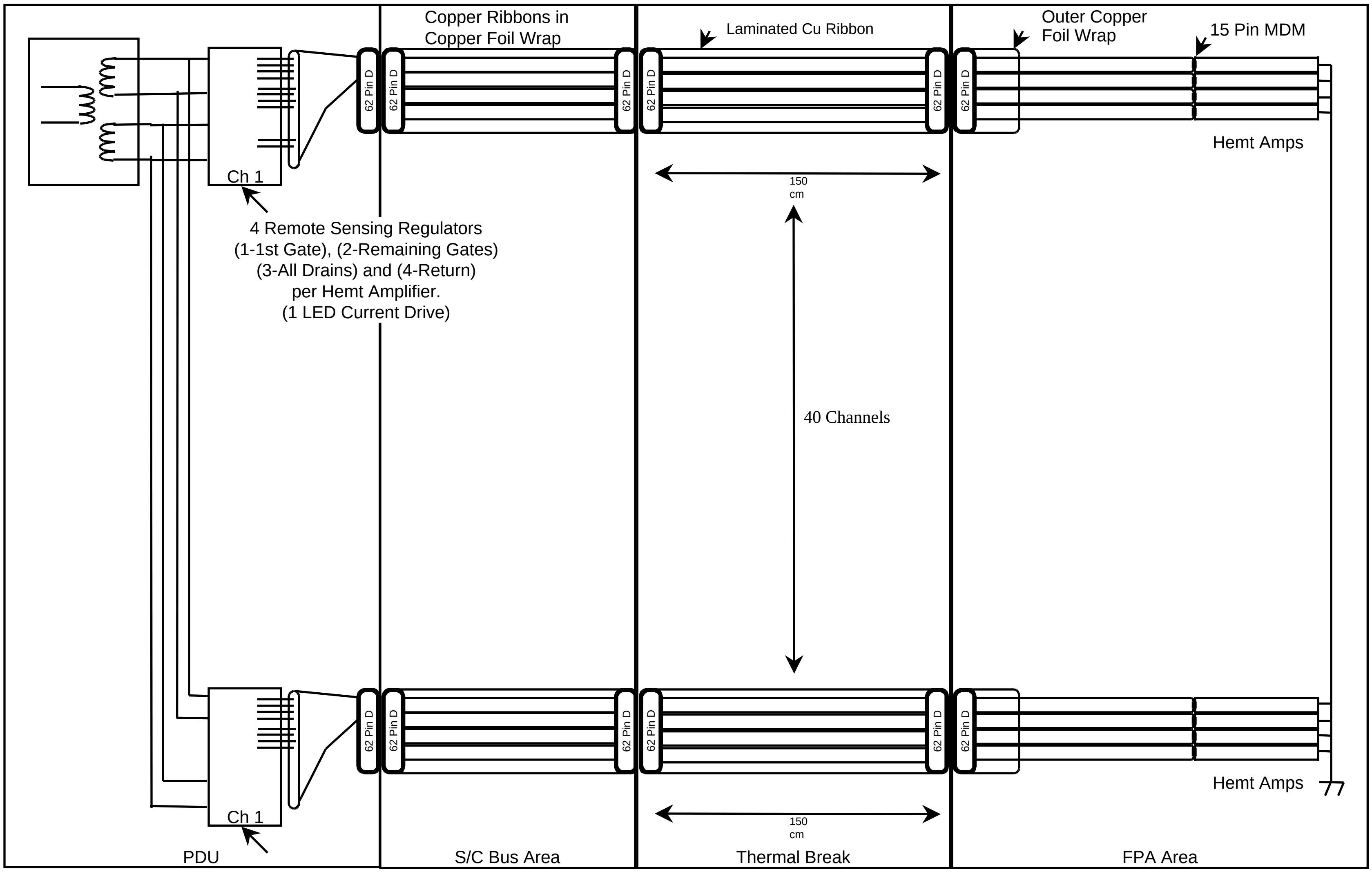
MAP Grounding Diagram

Instrument Electronics -- Backup Charts

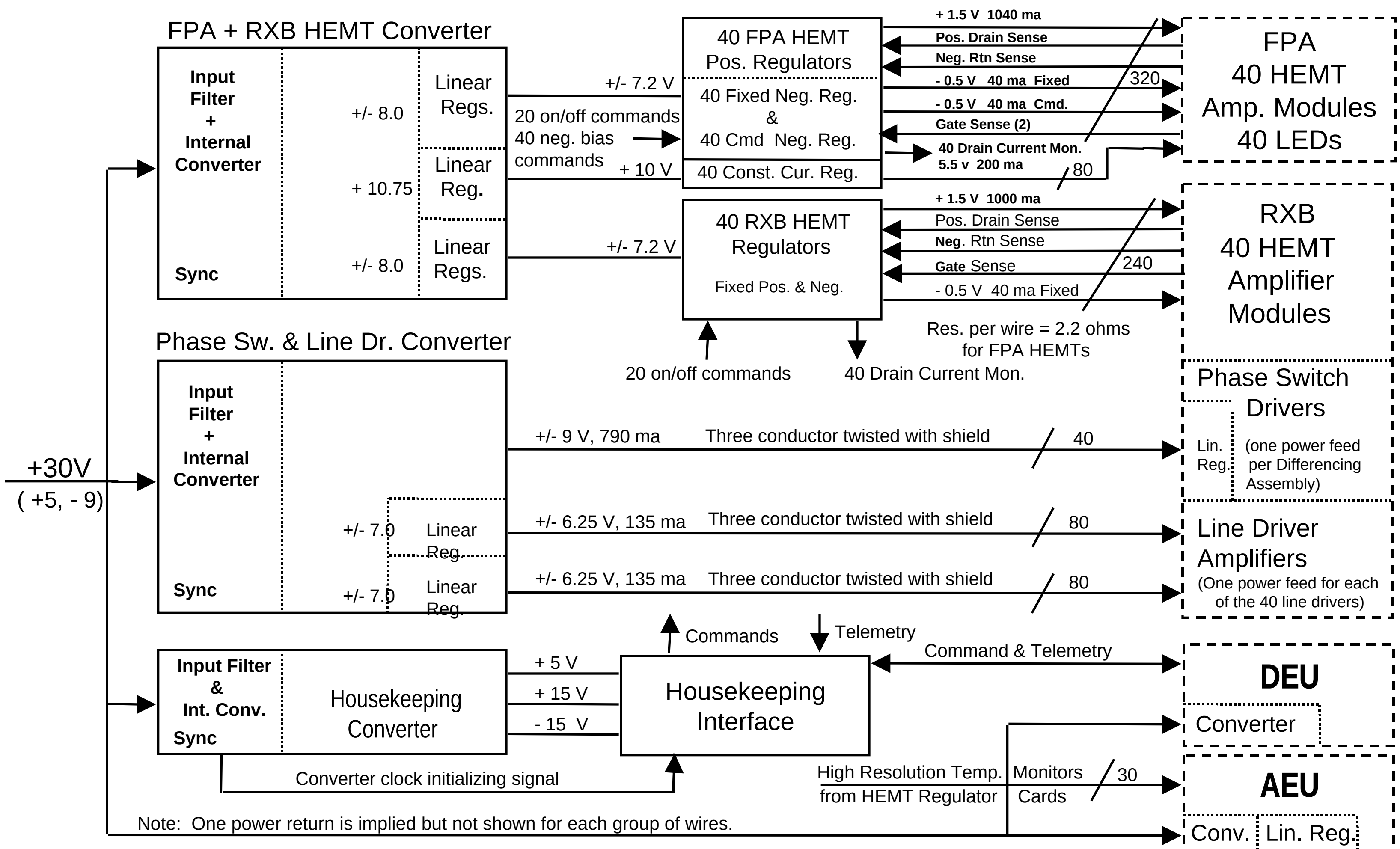


Cold Hemt Harnessing Detail

Instrument Electronics -- Backup Charts



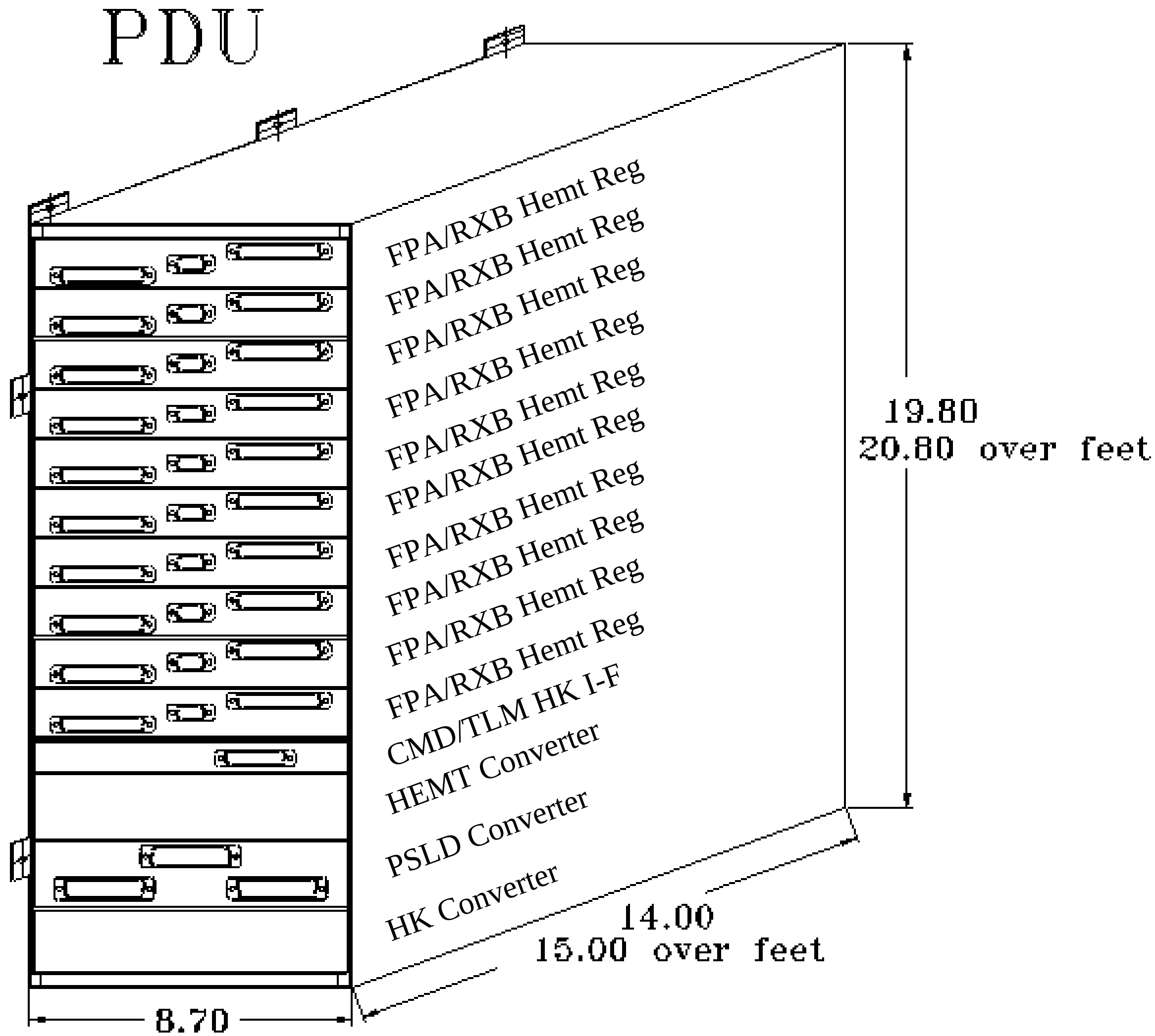
PDU Block Diagram



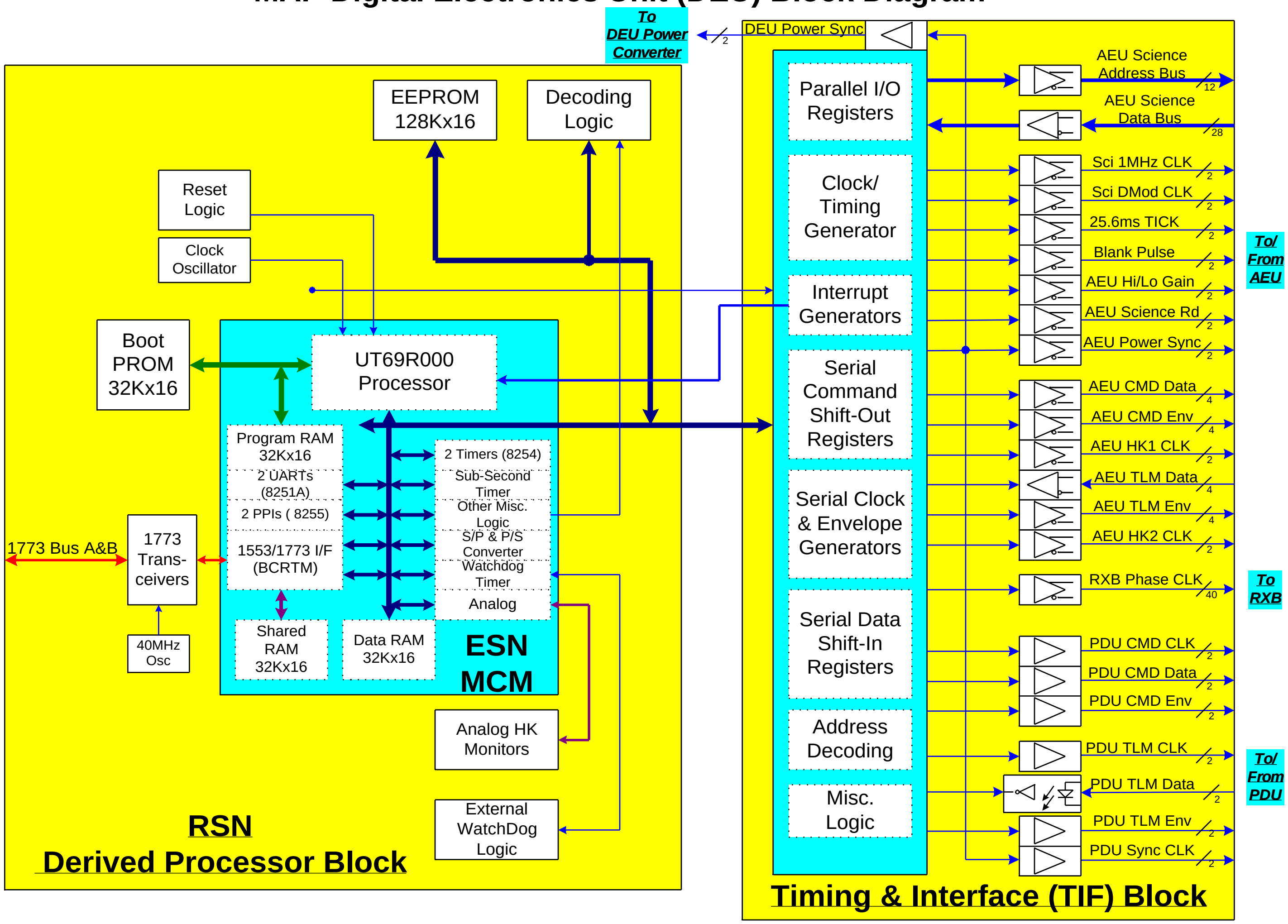
Map Power Distribution Unit (PDU) Block Diagram

12/1/98
Rev. 1.5

PDU Enclosure



MAP Digital Electronics Unit (DEU) Block Diagram



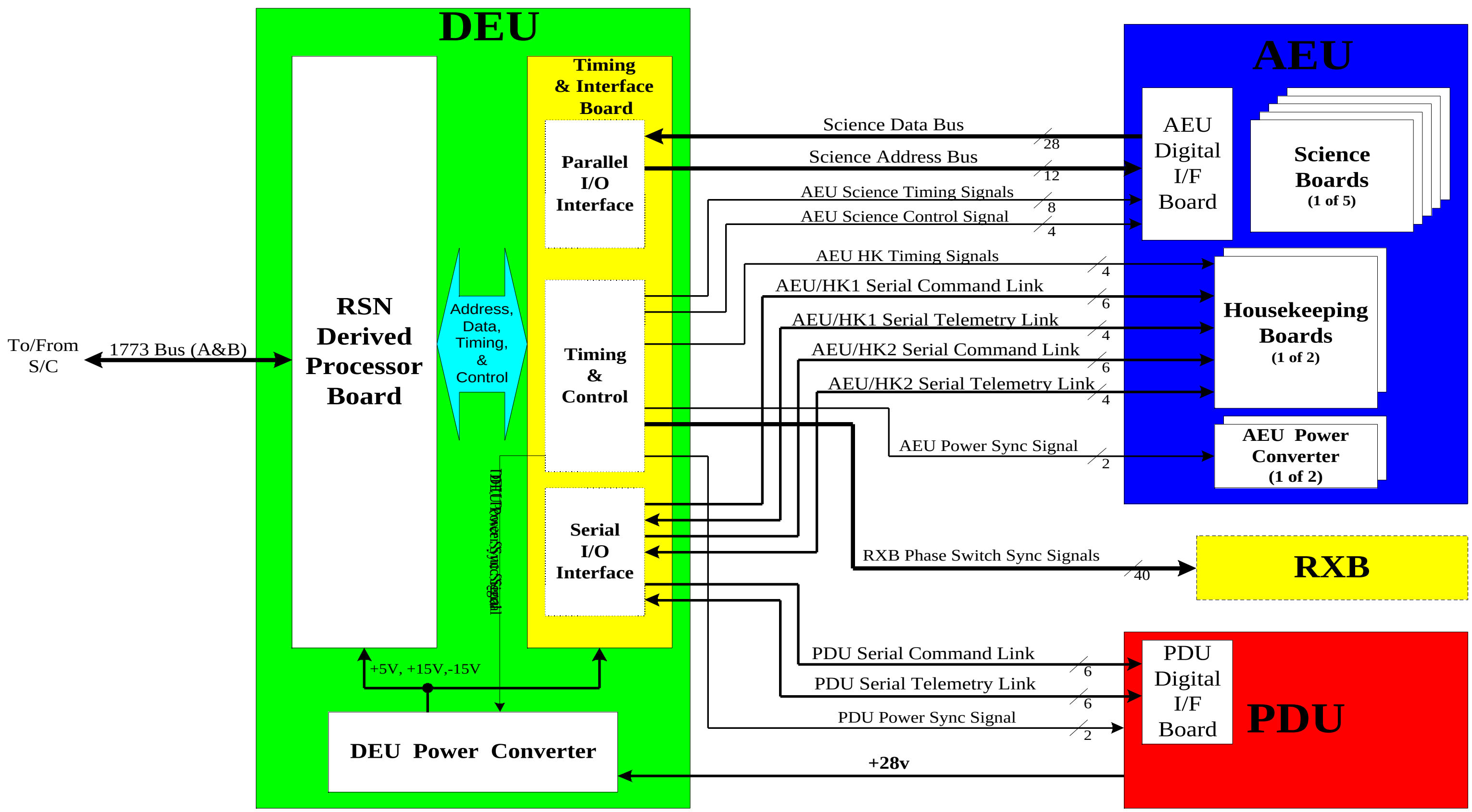
***Note:** Does not show power connections, nor DEU power converter*

RAB 2/28/97

DEU Interfaces

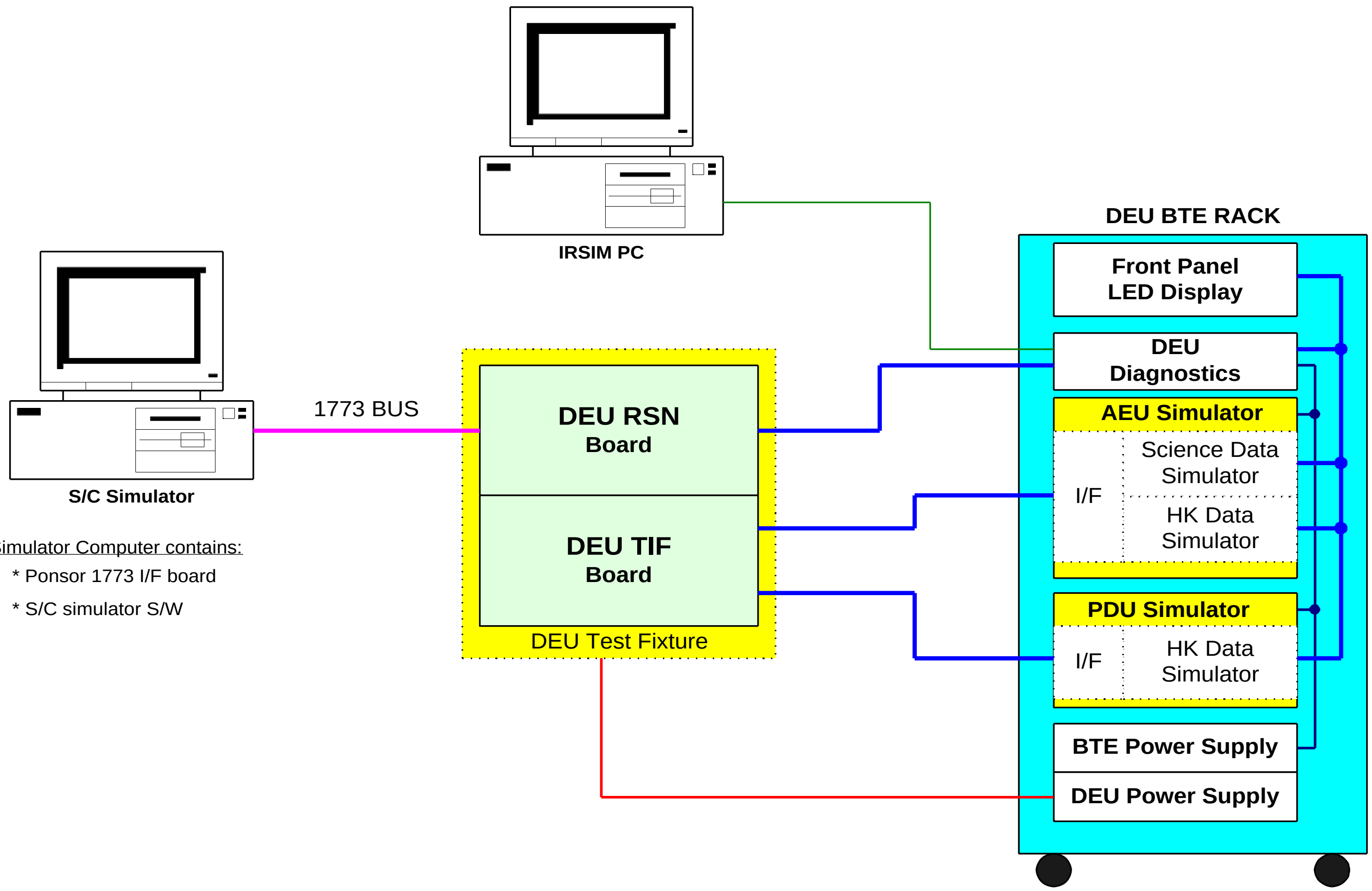
Instrument Electronics -- Backup Charts

MAP DEU Top-Level Interface Block Diagram



RAB
2/28/97

DEU BTE Block Diagram



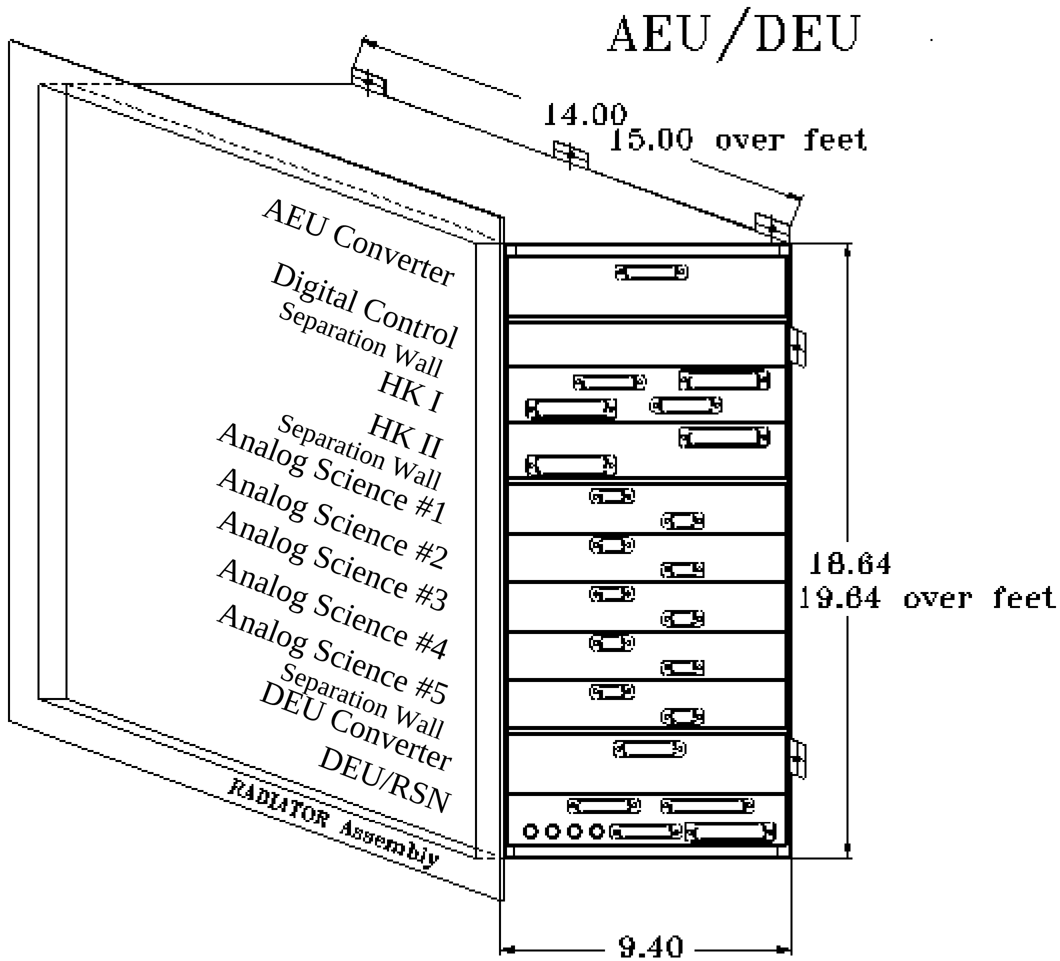
S/C Simulator Computer contains:

* Ponsor 1773 I/F board
* S/C simulator S/W

MAP DEU BTE BLOCK DIAGRAM

11/22/96
RAB

AEU/DEU Enclosure



Microwave Anisotropy Probe (MAP) Confirmation Review

Instrument Electronics -
Analog Electronics Unit (AEU)

David Bergman

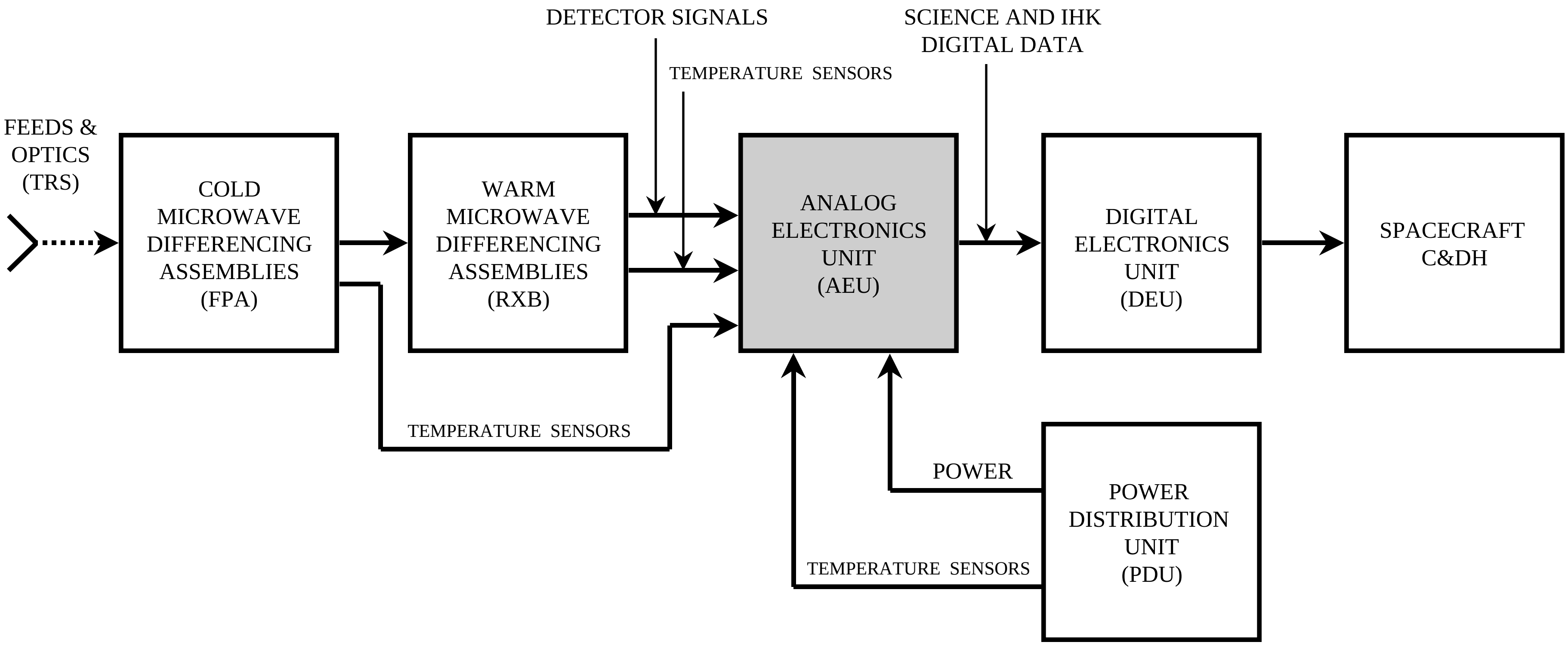
NASA/GSFC

code 564

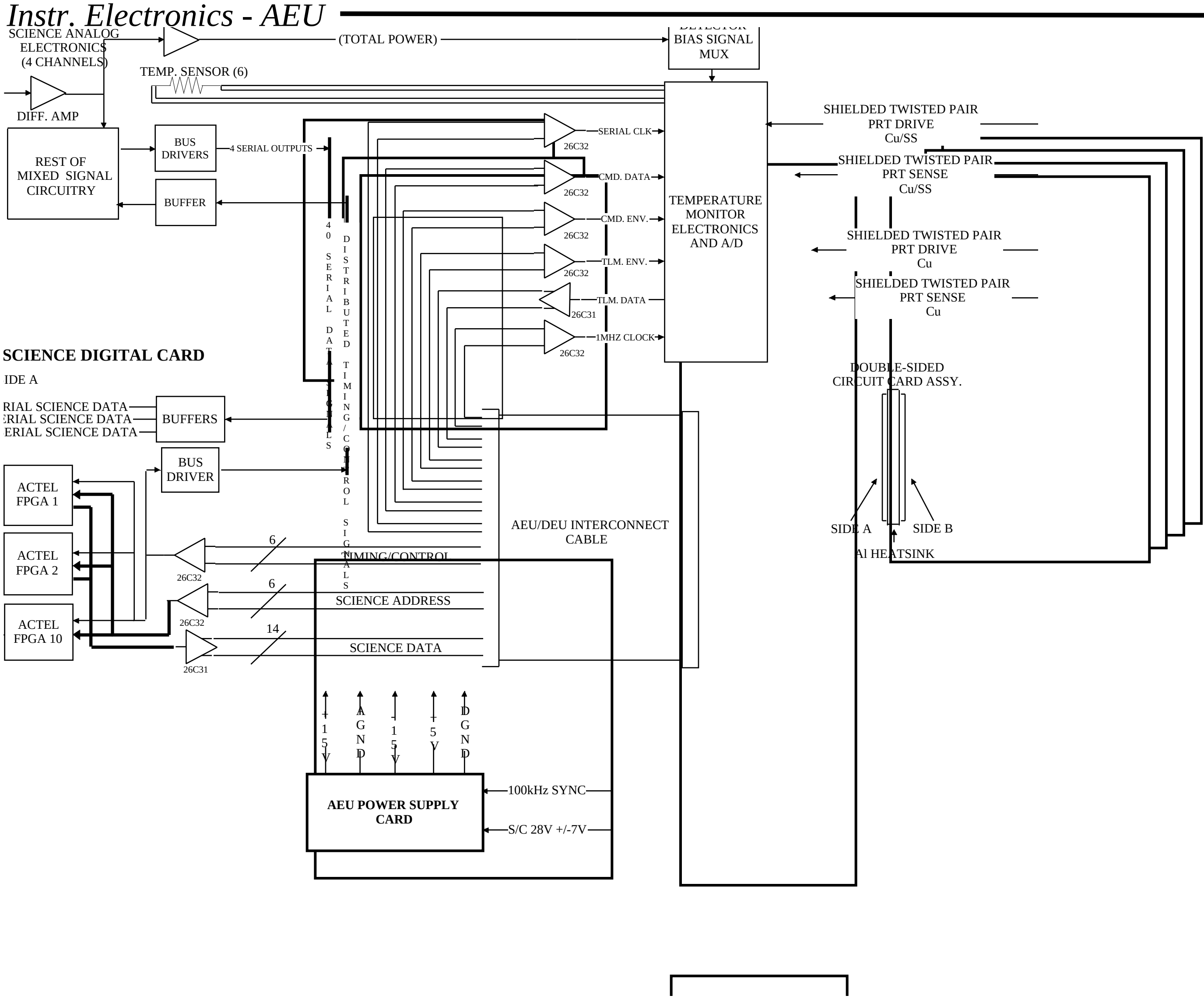
AGENDA

- Top Level Block Diagram
- Interfaces
- Salient Requirements
- Design
  - Science Electronics Block Diagram
  - Instrument Housekeeping (IHK) Electronics Block Diagram
  - Scope of Effort and Development Status
- Verification
  - Test Setup
  - Testing Status
  - LNVU Test Data
  - Flight Hardware Verification Flow

AEU IN THE SIGNAL CHAIN



Instr. Electronics - AEU



INTERFACES

- AEU/DEU
  - Science
    - data bus (14-bit, parallel)
    - address bus (6-bit, parallel)
    - timing/control - 1MHz, 2.5kHz clocks, 25.6ms tick, blanking pulse, high/low gain bit, Actel tri-state
  - Instrument Housekeeping (IHK)
    - serial link clock, data, and envelope for command and telemetry
    - A/D 1MHz clock

- AEU/RXB
  - 40 balanced, differential science data signals (RXB pre-amp/line drivers designed and built by GSFC)
  - 9 warm temperature sensors (4-wire)

INTERFACES, CONT'D

- AEU/TRS-FPA
  - 29 cold temperature sensors (4-wire)
- AEU/PDU
  - 6 warm temperature sensors (4-wire)
- AEU/Power Converter (S/C 28 +/-7V brought via PDU to internal converter card in AEU portion of AEU/DEU box)
  - analog power: +/-15V from internal power card
  - digital power: +5V from internal power card

SALIENT REQUIREMENTS

Excerpted from document AEU_Spec6.xls

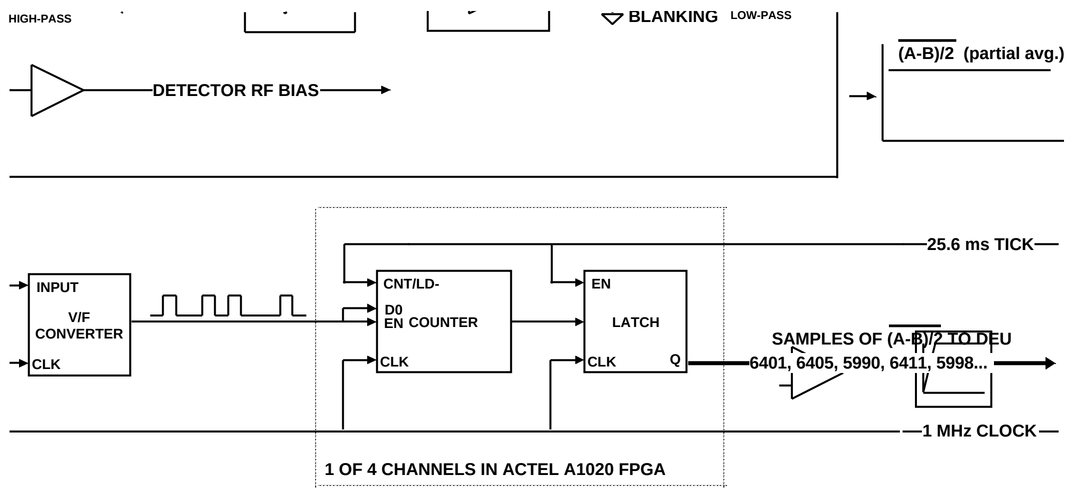
Functional Requirement	Performance Requirement	Verification
Science		
number of channels	40 (K-W bands)	design
input noise	< 150 nV/rtHz 2.5kHz-100kHz	analysis, test
input impedance	> 10 kohm dc -100kHz	design
input voltage range	-5V - 5V	design
high-pass filter	single pole, phase shift < 0.18 deg at 2.5kHz	analysis, test
low-pass filter	2-pole Bessel, f3dB = 100Hz	analysis, test
gain	G=14 K-band (4 channels)	design, test
	G=16 Ka-band (4 channels)	
	G=18, 20 Q-band (8 channels)	
	G=24 V-band (8 channels)	
	G=36 W-band (16 channels)	
bandwidth	100 kHz	analysis, test
spin synchronous gain stability	< 5 ppm rms	analysis, test
spin synchronous offset stability	< 500 nVrms	analysis, test
digitizer resolution	14-bits (1 part in 12800)	design, test
per-sample integration time	25.6 ms	design, test
demodulator clock frequency	2.5 kHz	design, test
blanking interval start	1 us before phase switch transition	design, test
blanking interval duration	5us (TBR)	design, test

REQUIREMENTS, CONT'D

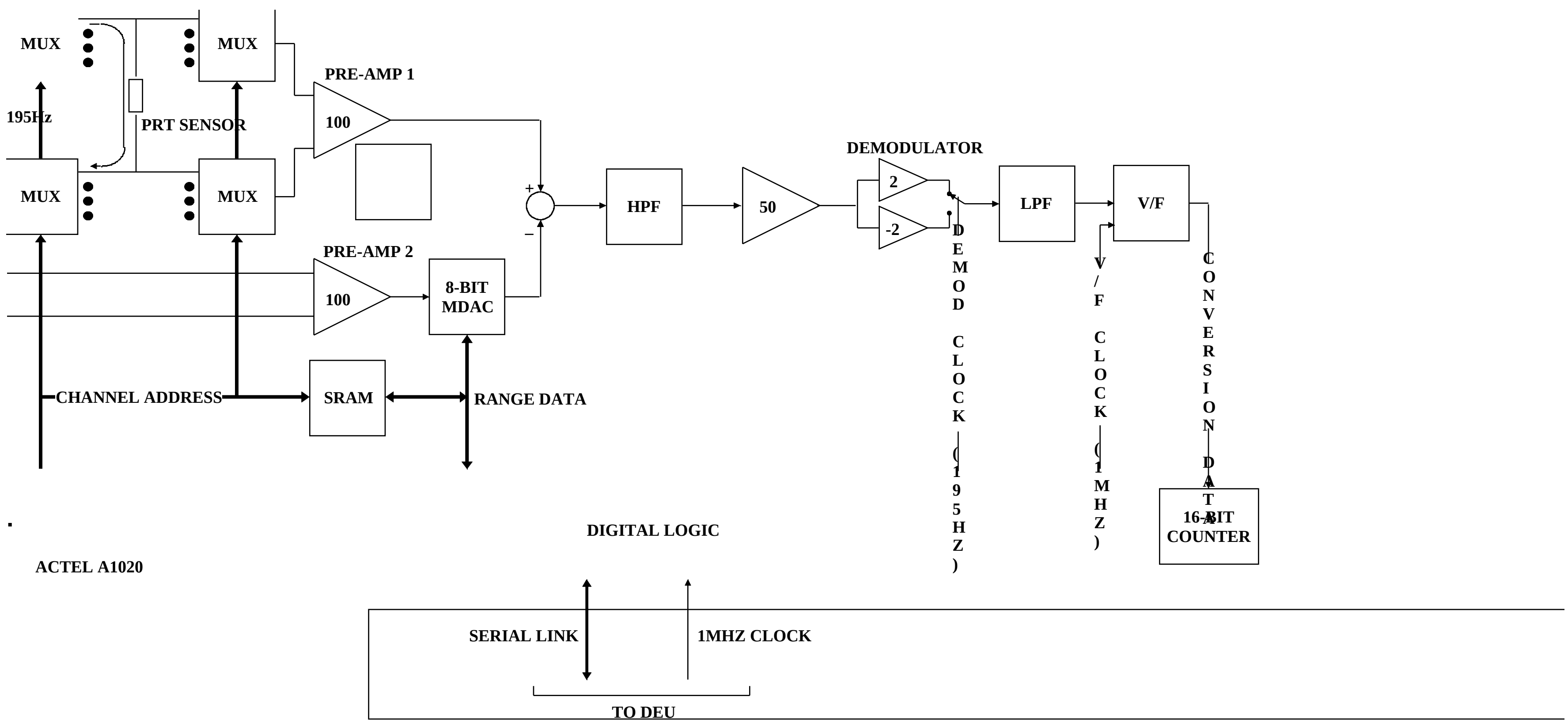
Excerpted from document AEU_Spec6.xls

Instr. Electronics - AEU

Functional Requirement	Performance Requirement	Verification
Detector RF Bias		
number of channels	40	design
sampling rate	4 samples/detector/spin	design, analysis
digitizer resolution	12 bits	design
bandwidth	7 Hz	design
Cold Temperature Monitors		
number of channels	32	design
sampling rate	4 samples/sensor/spin	design, analysis
range	40K-323K	design, analysis, test
absolute accuracy	+/-1K	analysis, test
sample-to-sample resolution	0.5mK, 40K-123K 100mK, 123K-323K	analysis, test
Warm Temperature Monitors		
number of channels	32	design
sampling rate	4 samples/sensor/spin	design, analysis
range	263K-343K	design, analysis, test
absolute accuracy	+/-1K	analysis, test
sample-to-sample resolution	0.5mK, 263K-343K	analysis, test
Environment		
operating temperature	0 - 40C at box radiator	test
radiation	AEU shall meet radiation requirements stated in Science and Mission Requirements Document	1. 27 kRad TID inside 100 mil Al sphere 2. 20 kRad inside S/C electronics box 3. See ray trace and dose depth analyses for TID inside instrument electronics box 4. > 35 MeV LET requires no analysis


HIGH-PASS
BLANKING
LOW-PASS
(A-B)/2 (partial avg.)
DETECTOR RF BIAS
25.6 ms TICK
INPUT
V/F
CONVERTER
CLK
CNT/LD-
D0
EN
COUNTER
CLK
EN
LATCH
CLK
Q
SAMPLES OF (A-B)/2 TO DEU
6401, 6405, 5990, 6411, 5998...
1 MHz CLOCK
1 OF 4 CHANNELS IN ACTEL A1020 FPGA

IHK BLOCK DIAGRAM



DEVELOPMENT STATUS

Instr. Electronics - AEU

H/W DEVELOPMENT FLOW

SCIENCE

BREADBOARD ANALOG
D. 8/96
B. 10/96

BREADBOARD DIGITAL
D. 8/96
B. 10/96

LNVU ANALOG
D. 1/97
B. 3/97

LNVU DIGITAL
D. 1/97
B. 3/97

LNVU JIG
D. 1/97
B. 3/97

10

PFU ANALOG
D. 5/97
B. 7/97

PFU DIGITAL
D. 5/97
B. 7/97

PFU BACKPLANE
D. 8/97
B. 10/97

INSTR. HOUSEKEEPING

BREADBOARD ANALOG
D. 2/97
B. 3/97

BREADBOARD DIGITAL
D. 2/97
B. 3/97

PFU ANLG./DIG
D. 7/97
B. 9/97.

BTE

RXB SIMULATOR
D. 10/96
B. 11/96

DEU SIMULATOR
D. 10/96
B. 11/96

INCLUDES SOFTWARE FOR:
1. SCIENCE DATA COLLECTION
2. HOUSEKEEPING AUTO-RANGING CONTROL

LEGEND

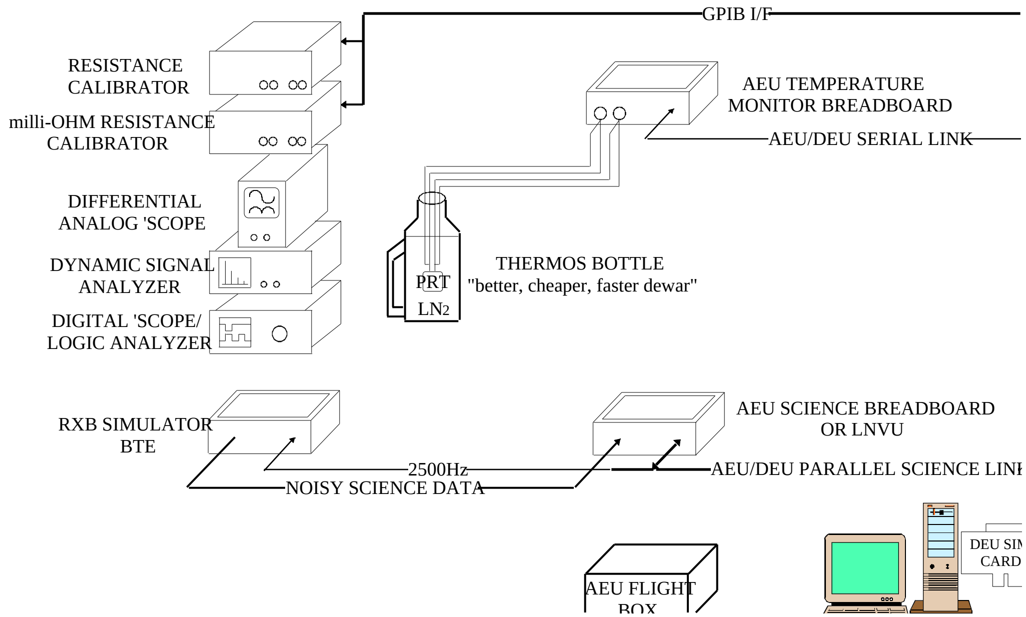
LNVU = LOW NOISE VERIFICATION UNIT (PSEUDO--ETU PRINTED CIRCUIT BOARD)

D. = SCHEDULED DESIGN COMPLETION
B.= SCHEDULED BUILD COMPLETION

STATUS

- - - - - - - - UPCOMING
———— IN LAYOUT
— — — — IN FAB
━━━━ BUILT

TEST SETUP



- Generic lab test equipment verifies parametric performance - filter corners, gains, rise times, logic timing, etc.
- 4 channel RXB simulator BTE simulates radiometer output noise and exercises science breadboard circuitry
- GPIB controllable calibrators and “cold PRT” resistance references provide simulated and real sensor inputs to the IHK circuitry
- PC based DEU simulator collects, stores, post-analyzes, and FTPs large amounts of real and simulated data

TESTING STATUS

- Science breadboard effort complete
  - integrated with breadboard Q-band radiometer at Princeton (10-11/96)

- Science LNVU PCB's (4 channels) testing complete
  - power consumption
  - logic timing
  - filter responses
  - channel-to-channel cross correlation
  - pixel-to-pixel autocorrelation
  - broadband noise
  - power supply rejection
  - temperature
    - general performance verification from -10C-50C in temperature chamber
    - small signal temperature response at 25C in temperature chamber

TESTING STATUS, CONT'D

- IHK breadboard testing nearly complete
  - power consumption
  - logic timing
  - broadband noise
  - overall dynamic range (>21 bits - 250μohm / 650 ohm)
  - overnight and weekend data-set collection to determine:
    - noise
      - 1.2 counts rms @ 125μK/count (100 ohm measurement)
      - 1.6 counts rms @ 125μK/count (500 ohm measurement)
    - channel-to-channel cross correlation
    - sample-to-sample autocorrelation
    - circuitry response to ambient temperature variations

LNVU TEST DATA

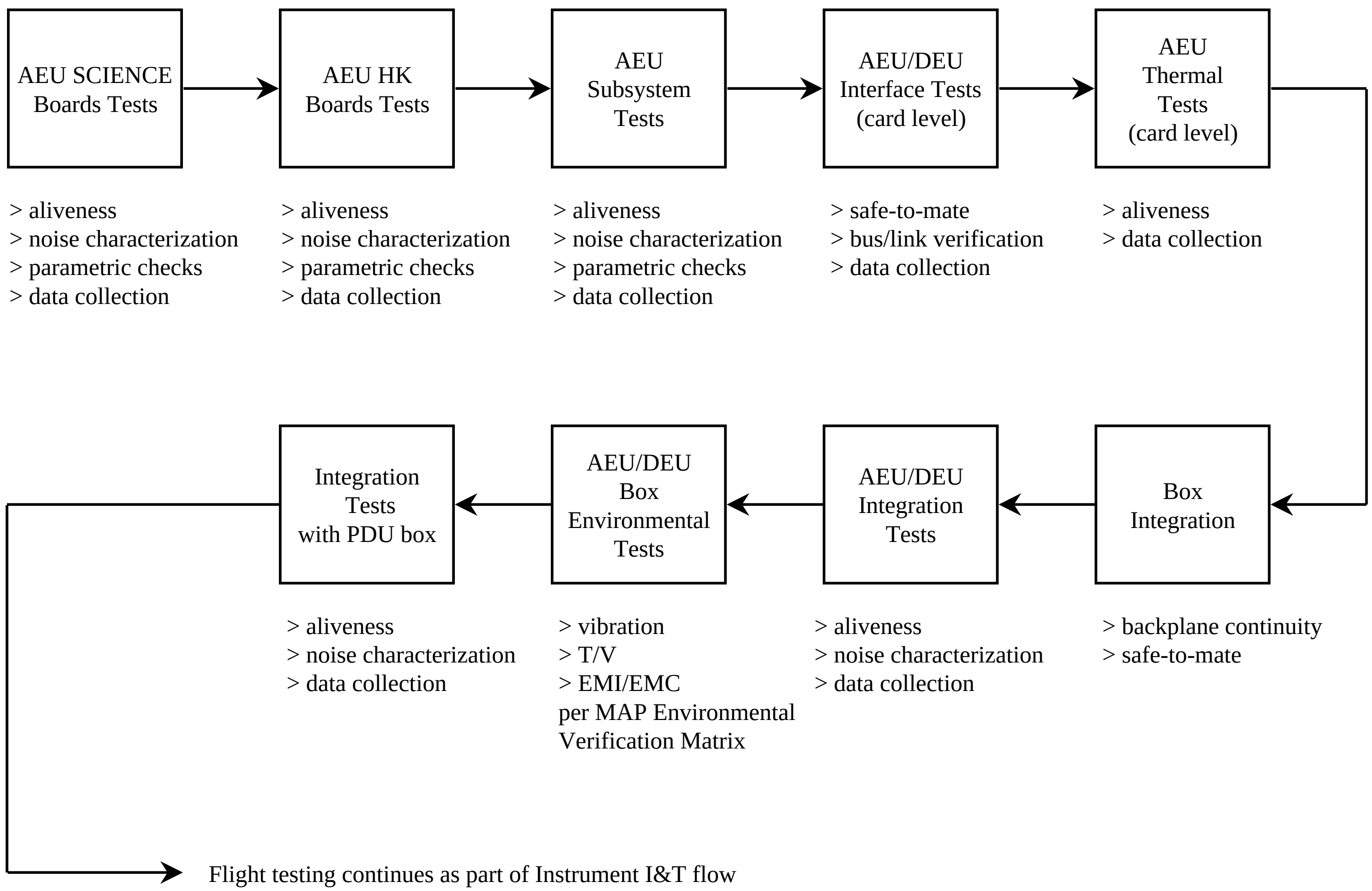
AEU's TOLL ON SYSTEMATIC ERROR BUDGET

(results obtained from moving average filtering of 2 hour datasets, approx. 300 ksamples each)

Forcing Function	AEU Parameter Affected	Change in Data	Change in Parameter	Systematic Error (assumes 1K rad. offset)	Data File
Temperature (1 deg. C Step)					
	post demod. offset	0.07 counts/C	55 uV/C	227 uK/C (K-band)	may15_1.bin
				329 uK/C (W-band)	
	overall gain	2(?) counts/C	400(?) ppm/C	400(?) uK/C (K-band)	jun3_1.bin
				400(?) uK/C (W-band)	
Supply Voltage (1V Step)					
	post demod. offset	.01 counts/Vs	8 uV/Vs	33 uK/Vs (K-band)	jun4_1.bin
				47 uK/Vs (W-band)	
	overall gain	0(?) counts/Vs	0(?) ppm/Vs	0(?) uK/Vs (K-band)	jun3_2.bin
				0(?) uK/Vs (W-band)	

PFU VERIFICATION FLOW

Instr. Electronics - AEU



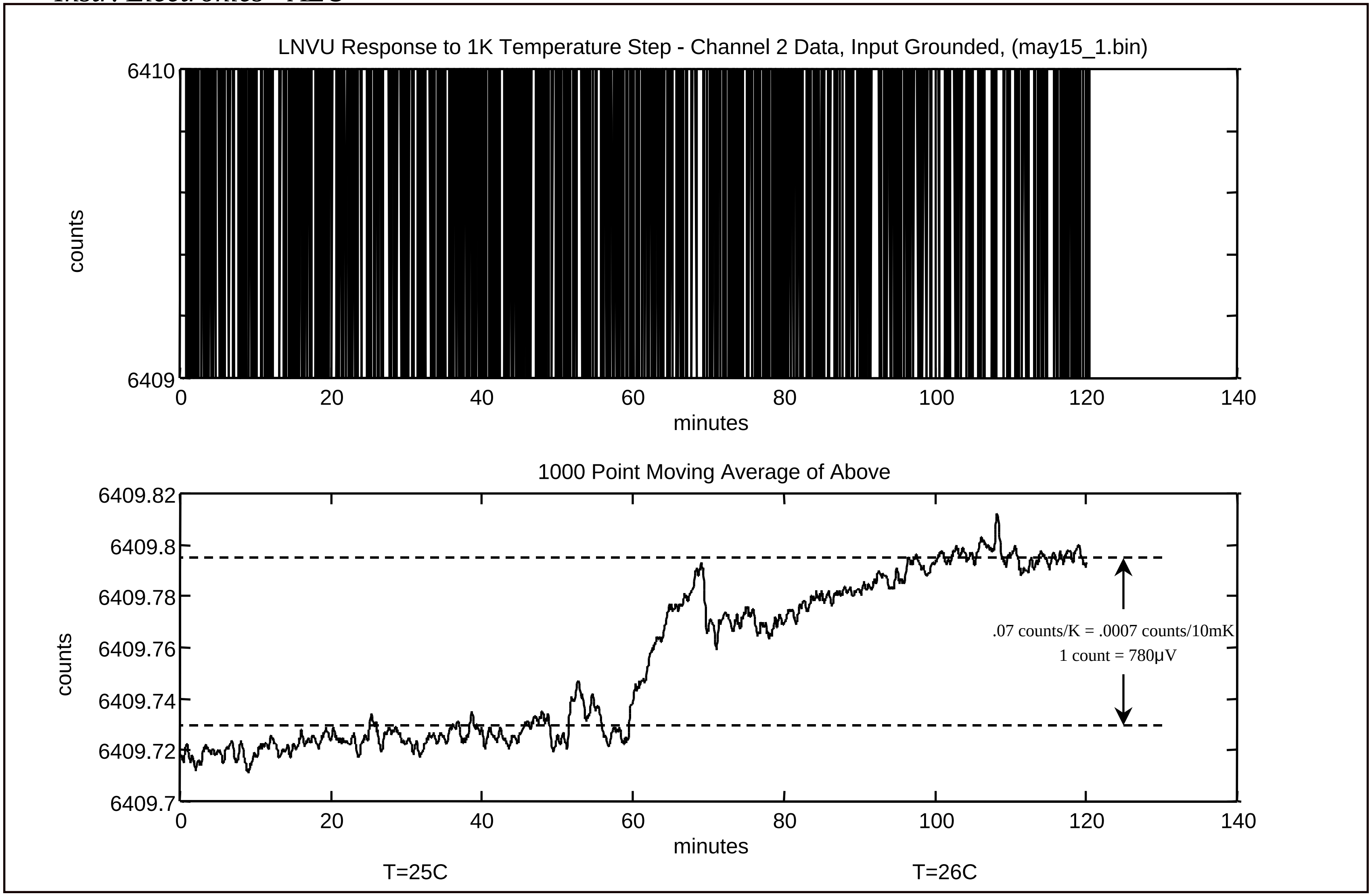
CONCLUSION

- Requirements and interfaces are defined, understood, and documented
- Science electronics breadboard effort is complete
- Science LNVU electronics bench testing is complete with lessons learned applied to flight schematic designs
- Documented LNVU test procedures serve as drafts of flight test procedures
- IHK breadboard bench testing is nearly complete with lessons learned applied to flight schematic designs
- All test data and descriptive notes reside on the ‘mapaeu’ PC and are accessable to all via FTP

END

LNVU TEST DATA (Spare Slide)

Instr. Electronics - AEU



Mechanical/Thermal Team

Mechanical/Thermal Subsystem

Jeff Stewart	722	Farhad Tahmasebi	721	Lee Niemeyer	722
Son Ngo	722	Alexia Lyons	721	Bob Coladonato	721
Alphonso Stewart	722	John McGuire	721	Sandra Irish	721
Carol Jones	722	Jim Loughlin	Swales	Scott Gordon	721
Dave Palace	722	Wayne Chen	Swales	Cynthia Curtis	Curtis
Mickey McDonald	722	Jeff Pattison	721	Angela Curtis	Curtis
Tad Driscoll	Swales	Frank On	721	Myron Bradshaw	Curtis
Bobby Nanan	Swales	Peter Mule	721	Dewey Dove	752
Ian Walker	Curtis	Kirk Rhee	724	Richard Freburger	752
Rich DiSorbo	Swales	Stu Glazer	724	Jerome Lindsey	752
Jeff Fuka	Swales	Jeff Didion	724	Ted Michelek	724
Suri Patel	Swales	Jay Parker	752	Don Guishard	PCI
Ben Rodini	Swales	Felicia Donnell	752	Clarence Hightower	PCI
Drew Jones	722	Alan Schuneman	701	Mike Viens	313
Markham Hacke	PCI	Dale Neverman	PCI	Brad Parker	313
Hans Neubert	PCI	Jeff Risse	PCI		

TRS Requirements

- Volume-Delta 10' Fairing (108" static envelope)
- Mass - shall not exceed 114.4 lbs. (52 Kg)
- Spin-Up and Spin-Down (70 rpm in approx. 2 seconds)
- Stiffness-Minimum Natural Frequency (MNF) of 40Hz.
- Strength -Positive margins using 1.4 (Ult.) and 1.25 (Yield) Factors Of Safety.
- Dimensional Stability (as shown in Spatial Resolution Error Budget).
- Provide 5.4 m^2 of radiator area.
- Provide support for required diffraction shielding and MLI blanketing.
- Contamination (visibly clean per JSC-SN-C00005 Rev C)

TRS Requirements

- Environmental conditions (as specified for launch, ground handling/test, on orbit environments)
- Operational Life (27 months)
- Solar Flux (2 hours exposure w/solar flux=0.92 W/inch^2.
- Surface Charging
  - resistivity of all external surfaces less than 1E9 ohms/sq.

TRS Structural Verification

- Coupon Tests: PCI required to perform/pass process ver. tests prior to fab of flight hardware & (at a minimum) verify the following if required in the design:
  - bonded/bolted joints
  - Flatwise Tensile Strength of Sandwich Const.
- Witness Samples (provided by PCI):
  - 2"x3" coupon from edge of each flight reflector surface.
  - 6"x6" flat sample coated in same process batch as flight reflectors
  - GSFC will perform Tape test (ASTM D3359-90,Method A) following thermal cycling to 77K and back to 383 K as well as absorptivity/emissivity verif.

TRS Structural Verification

REU Photogrammetry Test

REU Beam Mapping Test (with FPA #2)

<u>TRS Qualification Tests:</u>

Proof Test Lifting I/F

Modal Survey (if below 50 Hz)

Sine Sweep

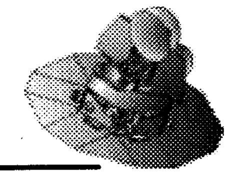
Strength Qual

Acoustic

Thermal Vacuum/Thermal Balance/ Alignment(Photogrammetry)

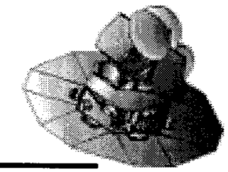
REU-Reflector Evaluation Unit

Microwave System Requirements

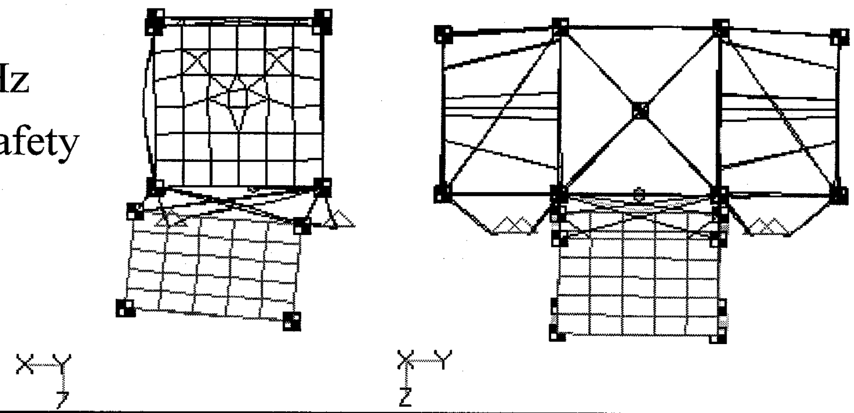


- Stiffness- Minimum Natural Frequency of 50Hz for FPA/RXB
- Strength- positive margins using 1.4 (Ult) and 1.25 (Yield) factors of safety.
- Minimize stresses in DA components.
- Provide thermal isolation of instr. from S/C (HEMT amps <95K).
- Provide accessibility for integration of DAs.

Microwave System Structural Analysis



Fundamental Vibration Mode ~55 Hz



- Normal Modes Analysis : MNF > 50 Hz
- Stress Analysis: Positive Margins of Safety

Governing Failure Modes

Item	Governing Failure Mode	Governing Load Case	Comments
Interface Cylinder	Buckling of Cylinder Wall	Launch Loads	M.S. = +0.30
FPA	Buckling of Truss Member	Launch Loads	M.S. = +0.19
RXB	Tension Yield of Strut	Launch Loads	M.S. = +0.30
Differencing Assy	Yielding of Waveguide Material	Cool Down	M.S. = 0 ~ 1 *

* Exact M.S. is dependent on final wave guide material selection and properties test

MAP

Mechanical/Thermal Subsystem

Microwave System Structural Verification

Pre-QTM Vibe Tests

Purpose:
-Pre-test levels/set-up/concept

Items:
- Flightlike Microwave System Structure for Vibe Fixture (No Interface Cylinder)
- Mass mock-up of QTM

Level:
-Qual

Vibe Tests:
-Sine Sweep,Sine,Random

QTM Vibe Tests

Purpose:
-Early Proof of Concept Test
-Component performance
-Method of Structural Attach

Item:
- Q-band D/A Prototype except for :
  - -additional flanges
  - -Wav./Guide Lengths
  - -1/2 mass mock-up

Level:
-Qual

Vibe Tests:
-Sine Sweep,Sine,Random

M/M DA Vibe Tests

Goal:
-Pre-test/proof of concept of
-Early retirement of risk.
-test two or three M/M(s) at a time as build-up sched.

Items:
-one mass mockup of each band type (total of six) flight D/A design

Level:
-Qual

Vibe Tests:
-Sine Sweep,Sine,Random

Flight DA Vibe Tests

Purpose:
-Component testing (include. line driver bds and phase switch bds.)
-Verify workmanship
-Verify method of structural attachment.

Items:
-Every D/A as schedule allows.

Level:
-Qual (first one of each band) Acceptance for others

Vibe Tests:
-Sine Sweep & Random

Microwave System Vibe Test

Purpose:
-Flight Acceptance.

Items:
-Flight D/As, Structure (no Interface Cylinder)
-Mass Mockup Feeds

Level:
-Acceptance

Vibe Test:
-Sine Sweep

Microwave System Struct. Qual Vibe Tests

Purpose:
-Structually qual M/W System structure.
-Proof of concept for I&T packaging/struct. attach.

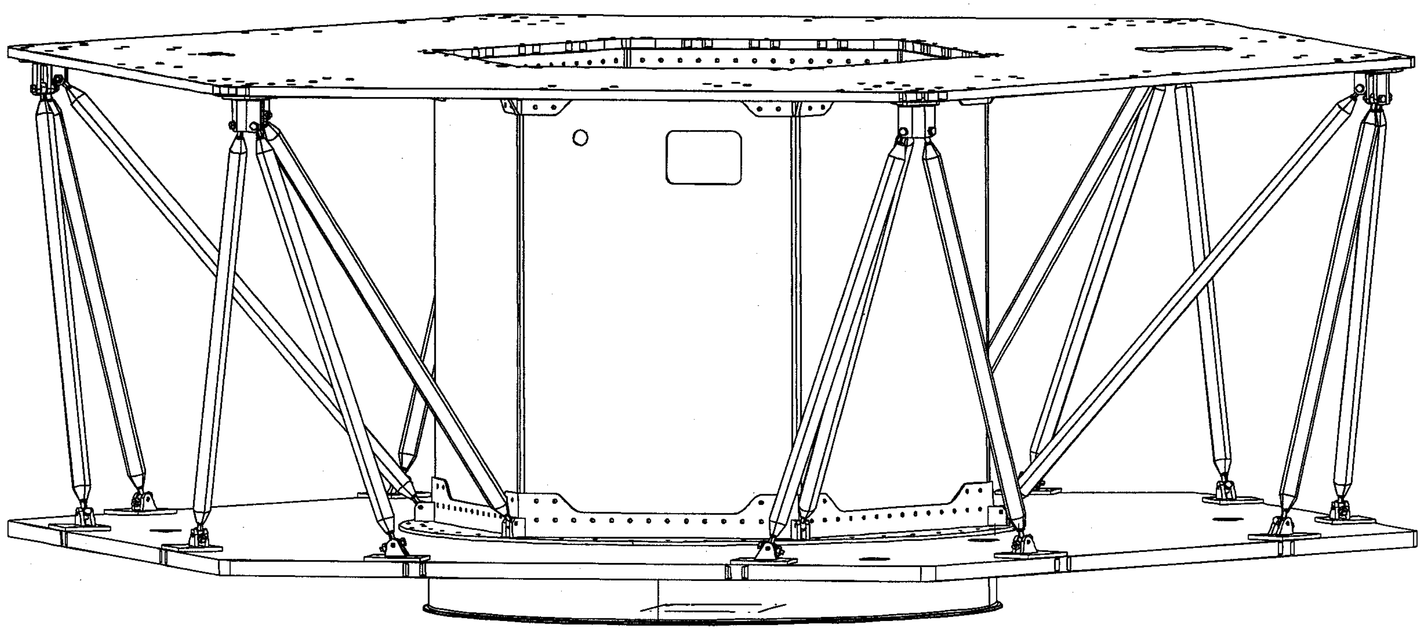
Items:
-FPA/RXB Struc #3
-Interface Cylinder
-M/M D/As (all)

Level:
-Qual

Vibe Tests:
-Sine Sweep, Sine, Random

Other Tests:
-T/V/TB and Photogrammetry

QTM -Qual Test Model
M/M - Mass Mockup
DA - Differencing Assembly



S/C Structure Requirements

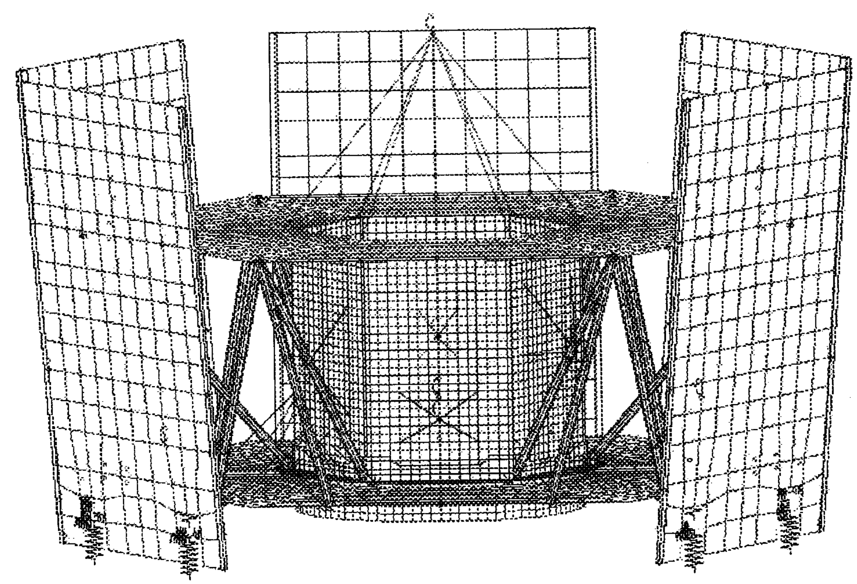
Mechanical/Thermal Subsystem

Requirement Parameter	Value	Source	Expected Performance	Basis	Verification Plan
On-orbit life	27 months	MAP-MSN-SPEC-01	>27 months	Design	-
Package/Interface to all components	-	MECH-SPEC ICD-SPEC	Compliant	Design	-
Provide clear FOV to components	Various	MAP-MSN-SPEC-01	Compliant	Design	-
Provide access on the gantry	Various	MAP-MECH-SPEC	Compliant	Design	-
Alignment	-	MAP-MSN-SPEC-01	Compliant	Design	Test
Delta launch (7325) Static envelope Loads Stiffness Band Clamp Tension Mass Properties	 108 in - 15Hz lat. 35Hz thrust 3300lbs -	 Launch Vehicle " " " "	 Compliant Compliant 20.8Hz lat. 47Hz thrust Compliant Compliant	 Design Analysis Analysis Analysis Analysis	 - Coupon & structural test Structural test Structural test MP test
On-orbit environment • Temperature • Radiation	 Various -	 THER-SPEC MAP-MSN-SPEC-01	 Compliant Compliant	 Analysis Analysis	 Analysis Analysis
Electrical grounding	2.5 mOhm	MAP-MSN-SPEC-02	Compliant	Design	Component an assembly test
Surface charging	1E9 Ohm/^2	MAP-MSN-SPEC-02	Compliant	Design	Assembly test
Contamination control	Class 100000	MAP-CONT-SPEC	Compliant	-	Cleaning procedures
Ground handling/Safety • Lifting load • Transportation load	 - -	MAP-MECH-SPEC	Compliant	Analysis	Proof test

MAP Spacecraft Structure Analysis

Mechanical/Thermal Subsystem

- Modeled to full allocated mass of 708 kg.
- Design of primary structure is stiffness driven.
- Fundamental Modes:
  - Lateral mode at 22 Hz.
  - Axial mode at 44 Hz.
- Analysis of composite joints correlated with tests results.
- Margins of safety:
  - Lowest margin is +0.19 for top hex ring flange.



MAP Spacecraft Margins of Safety

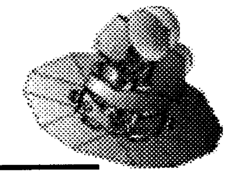
Mechanical/Thermal Subsystem

Structure	Failure Mode	F.S.	M.S.
Hex Hub Assembly			
Hex Hub to Top Ring	Bearing yield in aluminum	1.25	+ 3.56
Hex Hub to Bottom Ring	Bearing yield in aluminum	1.25	+ 1.46
Composite Hex Hub	Column Buckling	1.4	+ 1.93
Bottom Ring	Bending yield in aluminum flange	1.25	+ 0.54
Top Ring	Bending yield in aluminum flange	1.25	+ 0.19
PAF Transition Ring			
Bottom Ring I/F	Bending yield in aluminum flange	1.25	+ 1.91
Cylinder	Compression	1.4	+ 0.74
Secondary Structure			
Struts	Buckling	1.4	+ 4.43
Top Deck	Buckling due to lifting loads.	1.4	+ 4.39
Bottom Deck	TBD		
PAF Band Clamp	Exceeding peak line load.	1.25	+ 0.26

S/C Structural Verification

- Process verification for:
  - Hexhub-manufactured 9"hex hub (full diameter).
  - Top/Bottom Decks - vendor provided test coupons
  - Struts - compression/tension tests of bonded strut/fittings.
- S/C Tests (Protoflight - No ETU)
  - Lifting I/F proof
  - Modal Survey
  - S/A Depl (pre/post static)
  - Mass Properties
  - Alignment (pre/post static)
  - Static Load (HCC)

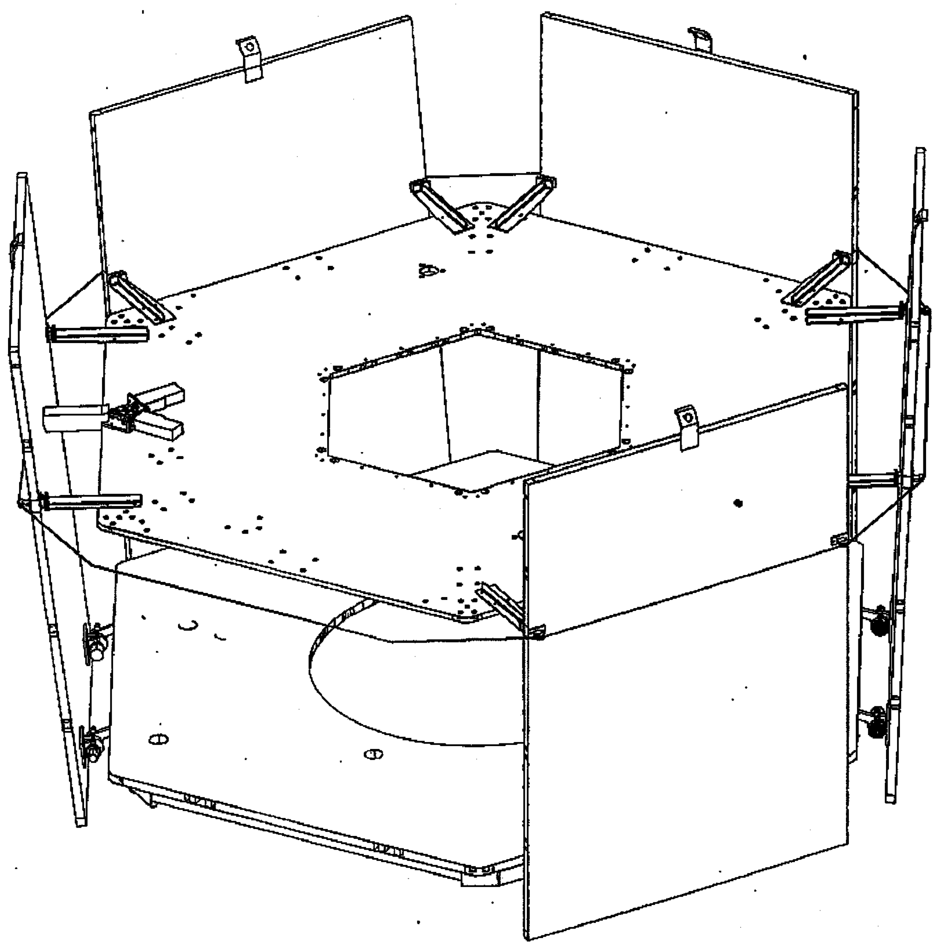
Requirements



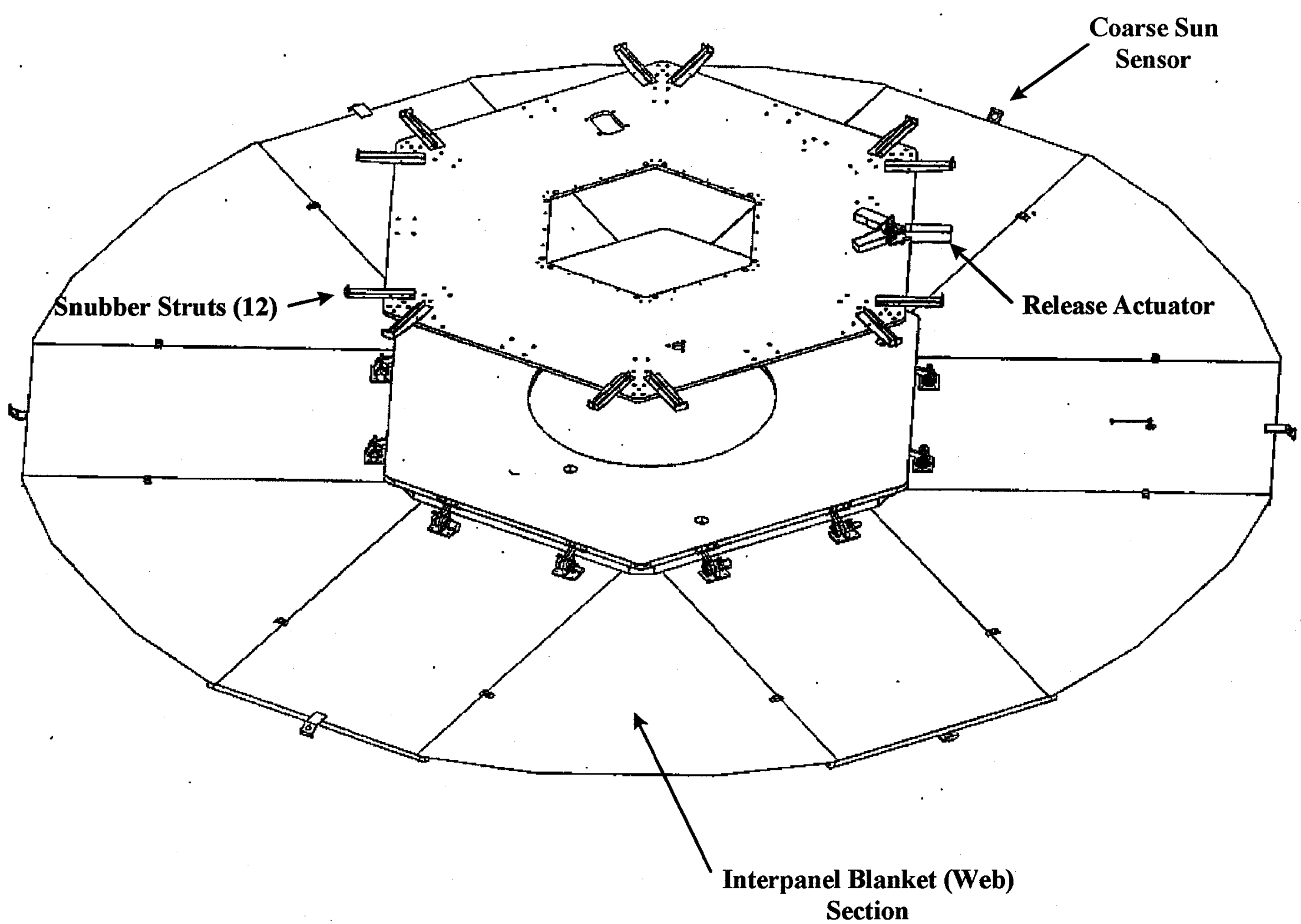
Solar Array Deployment System

- Provide platform for solar cell area of 3.1 M^2
- Position solar panels 90 +/- 1.0 deg. from spacecraft +Z axis and +/- 0.08 deg. about radial axis of each panel with respect to spacecraft X-Y plane.
- Deploy within 5 minutes of separation from third stage
- Provide complete sun shade of 27 deg. 1/2 cone angle from +Z axis for instrument and electronics box area after deployment.
- Provide coarse sun sensors platform for spherical coverage
- Maintain minimum deployed frequency of 1.0 Hz
- Stow within launch vehicle static envelope of 108 in diameter.
- Thermal: Pre-deployment -55 to 25 ^{o}C (Panel)
  (operating) -5 to 30 ^{o}C (Mechanisms)
- Design Loads: X=4.0, Y=7.5, Z=9.8 *(panel coordinate, x z in plane)*
- On-orbit accelerations 0.04 ft/sec^2 *(Thrusters)*
- Spacecraft radial force = 7.5 G's

Stowed Deployable System

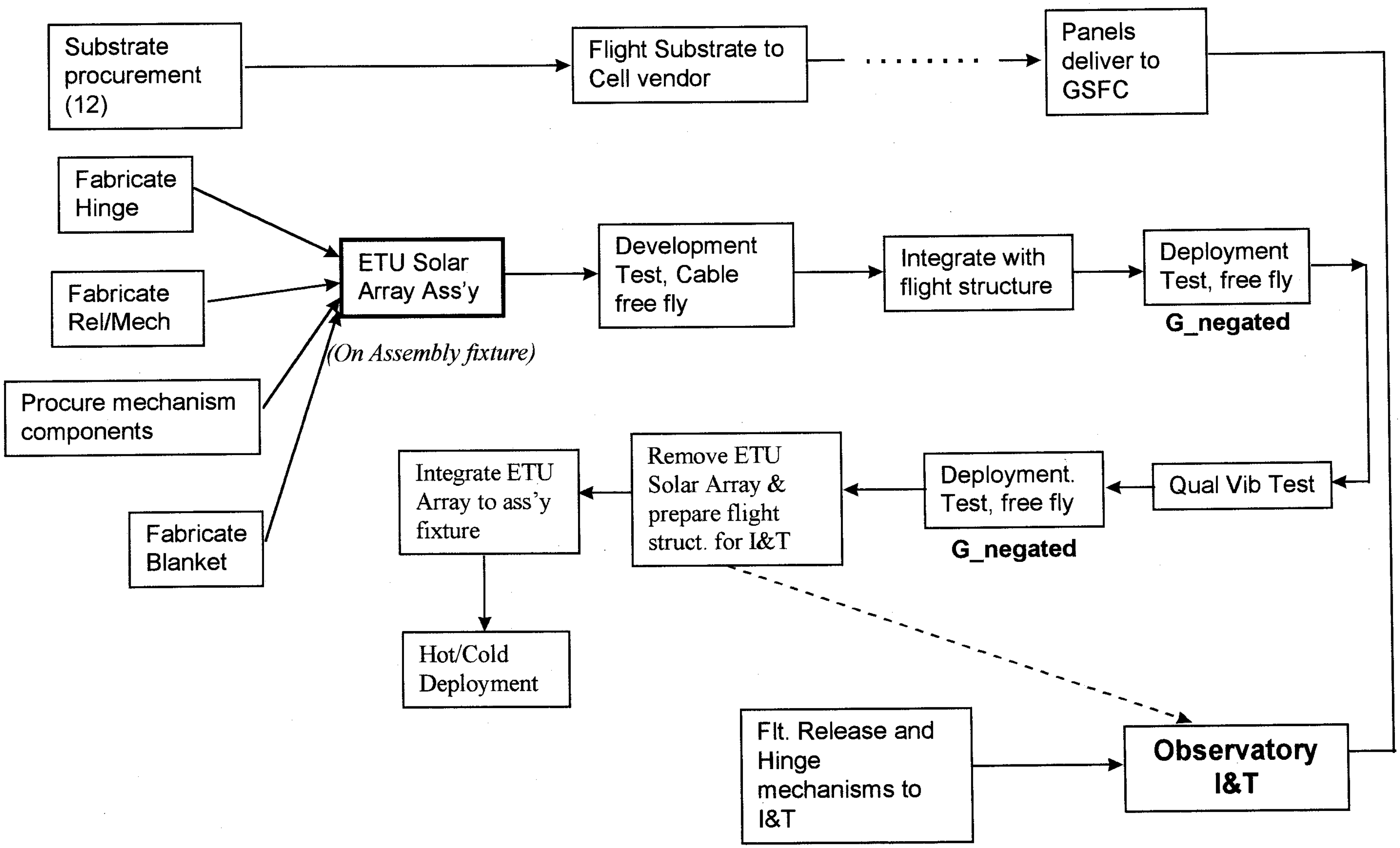


Deployed Solar Array System



Integration and Test Flow

Solar Array Deployment System



Flight Loads Analysis

Observatory C.G. Design Limit Loads

Flight Event	Axial Load* (g)	Lateral Load (g)
Liftoff/Transonic	+2.8/-0.2	±3.0
Prior to MECO	+6.7±0.6	±0.1
Third Stage Burn	+9.8	±0.1

The above levels have been verified using Base Drive Analyses and CLA.

Component CG Design Limit Loads

Component	Axial Load* (g)	Lateral Load (g)
TRS	+9.8/-0.7	12.0
FPA/RXB	+9.8/-0.8	7.8
Overall Instrument	+9.8/-0.7	7.0
Propulsion Tank	+9.8/-0.7	3.0
Solar Panels	+9.8/-2.8	7.5 (normal), 4 (in-plane)

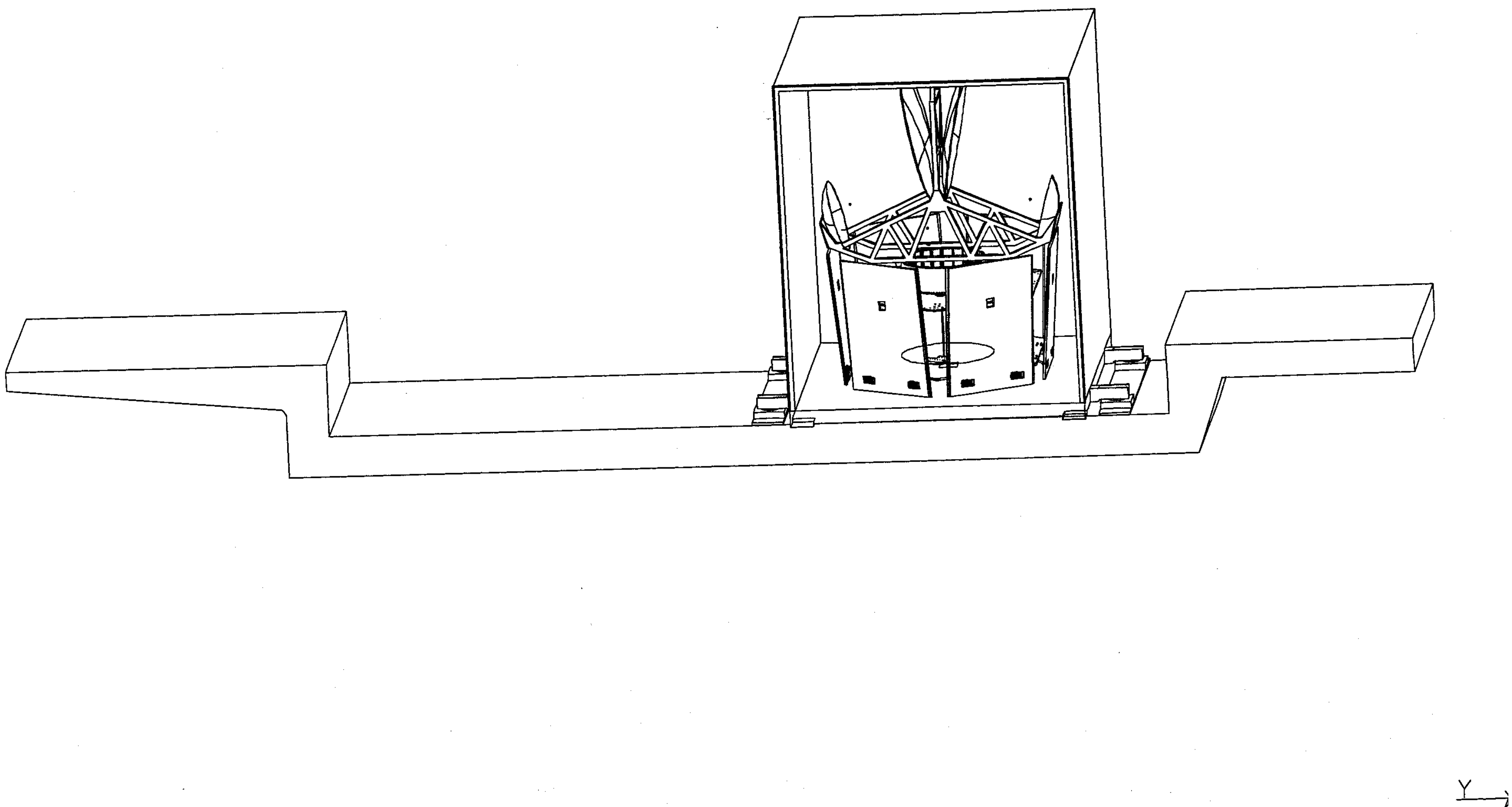
Component Design Loads have been obtained from Base Drive Analyses, and verified using CLA.

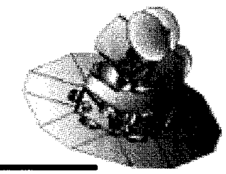
* *Plus indicates compression load and minus indicates tension load.*

Base Drive Analyses⟹ Liftoff, 1st pre-MECO, 2nd pre-MECO, Prior to MECO
CLA⟹ Liftoff, Transonic, Max-Q

Transporter

- Baseline - EUVE or TRMM Transporter with Observatory in vertical configuration.
- Transporting from GSFC to Kennedy Space Center by truck.
- Design for C5A (air shipment - optional)


Y



KENNEDY SPACE CENTER LAUNCH SITE SUPPORT

for the

Microwave Anisotropy Probe

(MAP)

Marion D. Thompson
Launch Site Support Manager
Kennedy Space Center / BR-C / KSC, FL 32899
Phone: (407) 867-3374 Fax: (407) 867-7644
Email: Marion.Thompson-1@ksc.nasa.gov

Launch Site

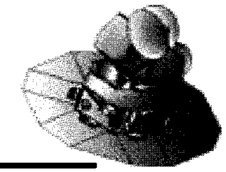
KSC HAZARDOUS PROCESSING FACILITY STATUS

FACILITY	CURRENT CAPABILITY	CURRENT PLAN FOR 2000	PROPOSED PLAN FOR 2000 (POP)
MPPF	Non-Hazardous	Bi-prop (under study)	Non-Hazardous
VPF	Mono-prop / Vertical Integration	Bi-Prop (under study) / Vertical Integration	Mono-prop / Vertical Integration
PHSF	Bi-prop	Bi-prop / Spin	Bi-prop
SAEF-2	Bi-prop / Spin	CLOSE	Bi-prop / Spin

FACILITY WEB SITES : (5/28/97)

http://www.ksc.nasa.gov/payloads/lssm/facility/mppf.html
http://www.ksc.nasa.gov/payloads/lssm/facility/phsf.html
http://www.ksc.nasa.gov/payloads/lssm/facility/saef2.html
http://www.ksc.nasa.gov/payloads/lssm/facility/lc17.html

MAP PAYLOAD PROCESSING AT KSC



Launch Site

CURRENT FLOW		PROPOSED FLOW
MPPF	**INTEGRATION AND TEST**	**SAEF-2** (PHSF *)
@ 1 week impact to procesing schedule		
PHSF	**PROPELLENT LOADING AND SPIN BALANCE**	**SAEF-2** (PHSF *)
SLC-17	**VEHICLE INTEGRATION AND LAUNCH**	**SLC-17**

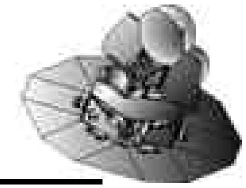
(PHSF *) If SAEF-2 Closes and Spin Balance Capability Moves to PHSF

SUMMARY OF FACILITY ISSUES

- **ASSUME SAEF-2 CLOSURE (Current Plan)**
  - SAEF-2 Planned Closure Leaves Singular Bi-prop Facility
  - Possibilty of multiple needs for Bi-Prop Facility - MARS Missions Require Bi-prop Facility; Discovery and ACRV Unknown
  - Worst Case : MAP Would Utilize MPPF and Move to PHSF for Propellent Loading and Spin*
  - Best Case : MAP could process through PHSF through coordination with MARS Program

- **ASSUME SAEF-2 OPEN (Proposed Plan)**
  - MAP is shown in SAEF-2 - but is STILL UNDER REVIEW
  - MARS Missions have priority for SAEF-2 due to prior processing through the facility and the need for both Bi-prop/Spin requirements
  - Worst Case : MAP may use MPPF or PHSF even if SAEF-2 remains open and move to SAEF-2 for Propellent Laod and Spin*
  - Best Case : MAP uses SAEF-2 for entire payload flow

*** @ one week impact to processing**



Launch Service for the MAP Mission

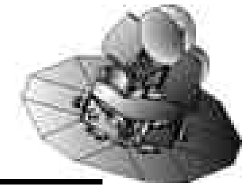
June 18, 1997

Diane Silva/OLS

MAP Mission Requirements

- Orbit Elements
  - C_3 = -2.6 km^2/sec^2
  - Inclination 28.7 degrees
  - Perigee 185 km
  - Argument of perigee is a function of launch month
- Payload mass 708 kg (vehicle capability)
- Second stage probability of command shutdown 99.7%
- 0.5 degree/sec roll rate during coast, roll axis normal to sun line
- Despin by Delta to 0 ± 2.0 rpm
- Nitrogen purge requirement TBD

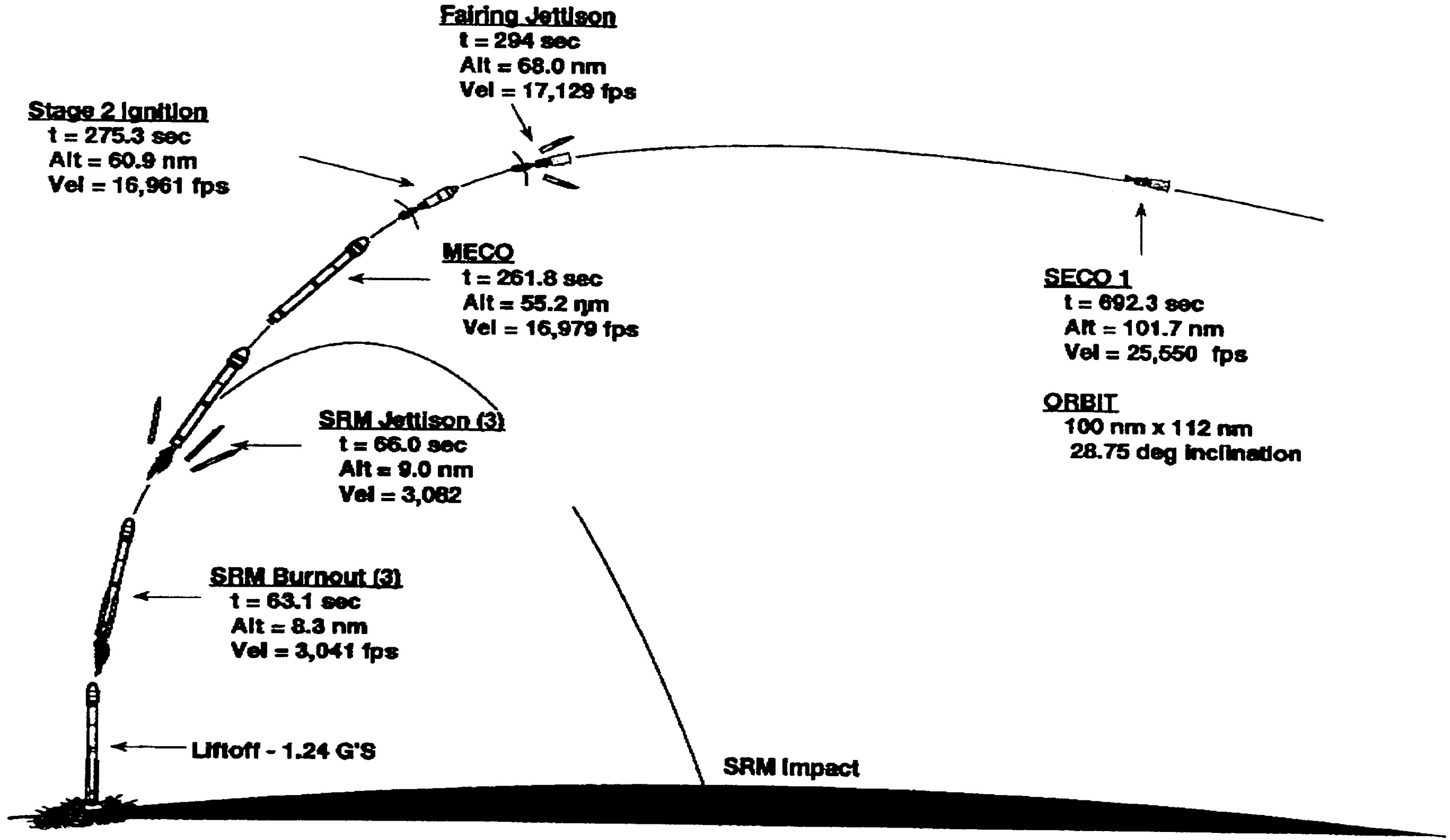
Preliminary Sequence of Events



EVENT	TIME(sec)
Liftoff	0.0
Mach 1	35.7
Maximum Dynamic Pressure	51.8
Solid Motor Burnout	63.1
Solid Motor Separation	66.0
Main Engine Cutoff	261.8
Vernier Engine cutoff	267.8
Stage 1/2 Separation	269.8
Stage 2 Ignition	275.3
10 ft Fairing Separation	294.0
First Stage 2 Cutoff	692.3
Start Stage 3 Ignition time delay relay, fire spin rockets	4395.4
Stage 2/3 Separation	4398.4
Stage 3 Ignition	4435.4
Stage 3 Burnout	4511.2
Deploy Yo-Yo weights	4805.4
Spacecraft Separation	4810.4

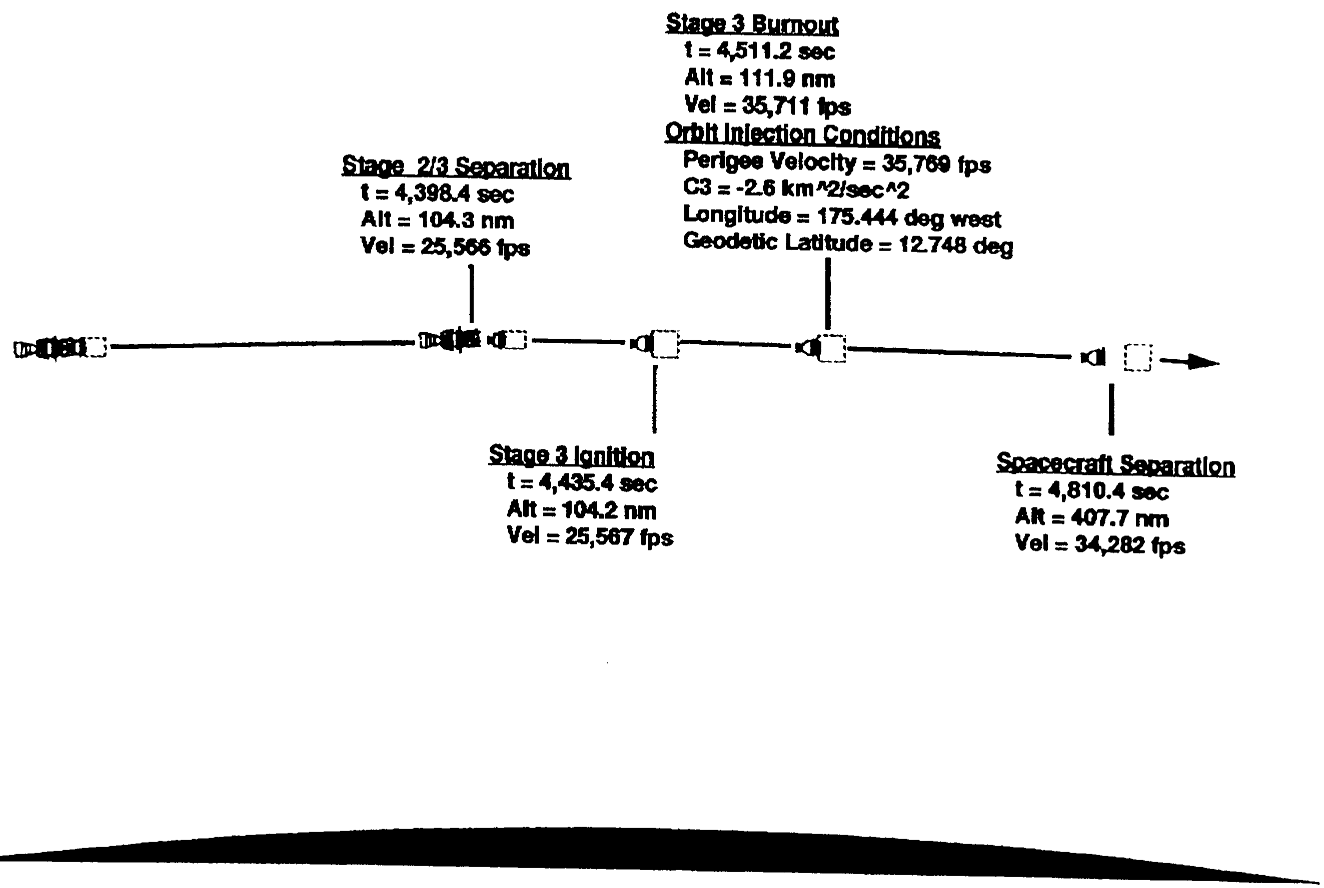
Delta 7325-10 MAP Mission
Preliminary Boost Phase Profile-ML TA-044

McDonnell Douglas-Space Transportation Division

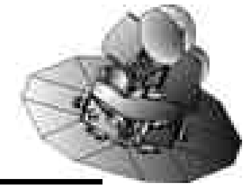


Delta 7325-10 MAP Mission
Preliminary Orbit Injection Profile-ML TA-044

McDonnell Douglas-Space Transportation Division



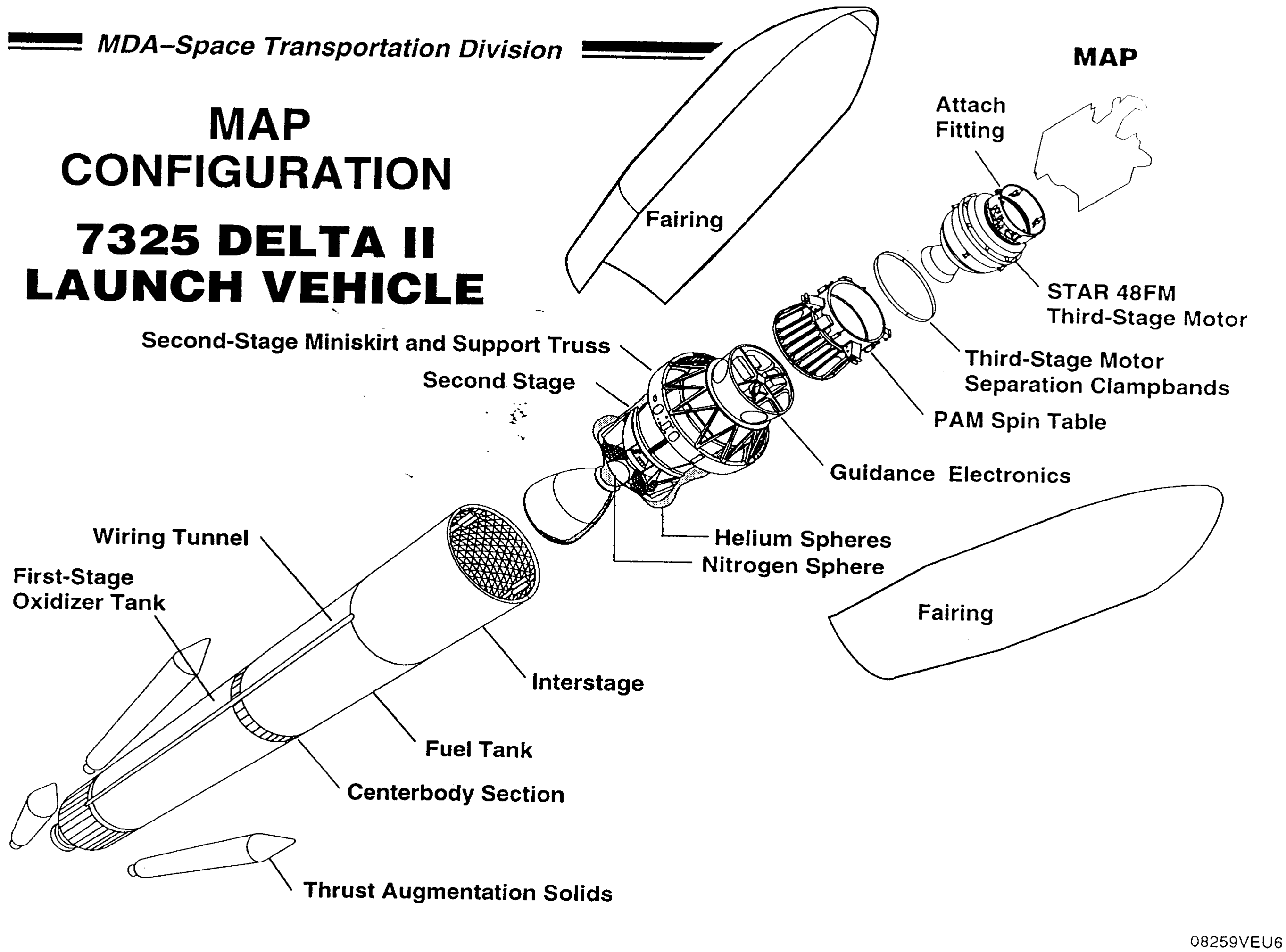
Orbit Dispersion Estimates



- Preliminary orbit dispersions have been generated by MDA based on 3σ errors of 0.5% in Star 48B Isp and 2.0 degree pitch/yaw pointing errors.
- Pointing error is a strong function of spacecraft mass properties.
- Final orbit dispersions are provided in the Preliminary Mission Analysis (PMA).
- Preliminary dispersions
  - Perigee altitude ±9 km
  - Injection velocity ±15.5 m/sec
  - Inclination ±0.40 deg
  - Flight path elevation ±0.57 degree
  - Flight path azimuth ±0.57 degree

MAP Launch Vehicle Configuration

- Delta 7325
  - MAP will be the 4th 73xx mission flown
  - DS-1 in 7/98, FUSE in 10/98, IMAGE in 1/00
- Offloaded Star 48B
  - ~478 lbs of propellant will be offloaded
  - Motor qualed up to 612 lb of offload
- Yo-yo despin system
  - Already flown on 5 missions (Kopernikus, Ulysees, Wind, MGS, Pathfinder)
  - Will fly on DS-1, Mars Orbiter, Mars Lander, IMAGE
- 10 ft composite fairing
  - First flight of composite was Iridium 5/5/97
  - 20 more 10’ fairing flights planned prior to MAP


MDA–Space Transportation Division
MAP CONFIGURATION
7325 DELTA II LAUNCH VEHICLE
MAP
Attach Fitting
Fairing
STAR 48FM Third-Stage Motor
Third-Stage Motor Separation Clampbands
PAM Spin Table
Guidance Electronics
Second-Stage Miniskirt and Support Truss
Second Stage
Helium Spheres
Nitrogen Sphere
Fairing
Wiring Tunnel
First-Stage Oxidizer Tank
Interstage
Fuel Tank
Centerbody Section
Thrust Augmentation Solids
08259VEU6

Star 48B Propellant Offload

- An offloaded motor is required to match the MAP C_3 requirement.
- The original Star 48 motor qualification considered two grain configurations.
  - 10 static firings with a full propellant load (4405 lb)
  - 4 static firings with a 13% offload (3833 lb load)
  - The only flight with an offload was a 4300 lb configuration (2.4% offload) flown on SBS-C, an STS mission 7/15/82.
- The Star 48B motor has flown 59 flights on STS and Delta, all fully loaded (4430 lb) and successful.
  - The change from Star 48 to Star 48B is the nozzle only.
- Thiokol considers offloads up to 20% are achievable and that offloads within the 3833-4430 lb range are qualifiable by analysis
- The offload required for MAP is about 480 lb (10.8% of the 4430 lb load).

Star 48B -Cont'd

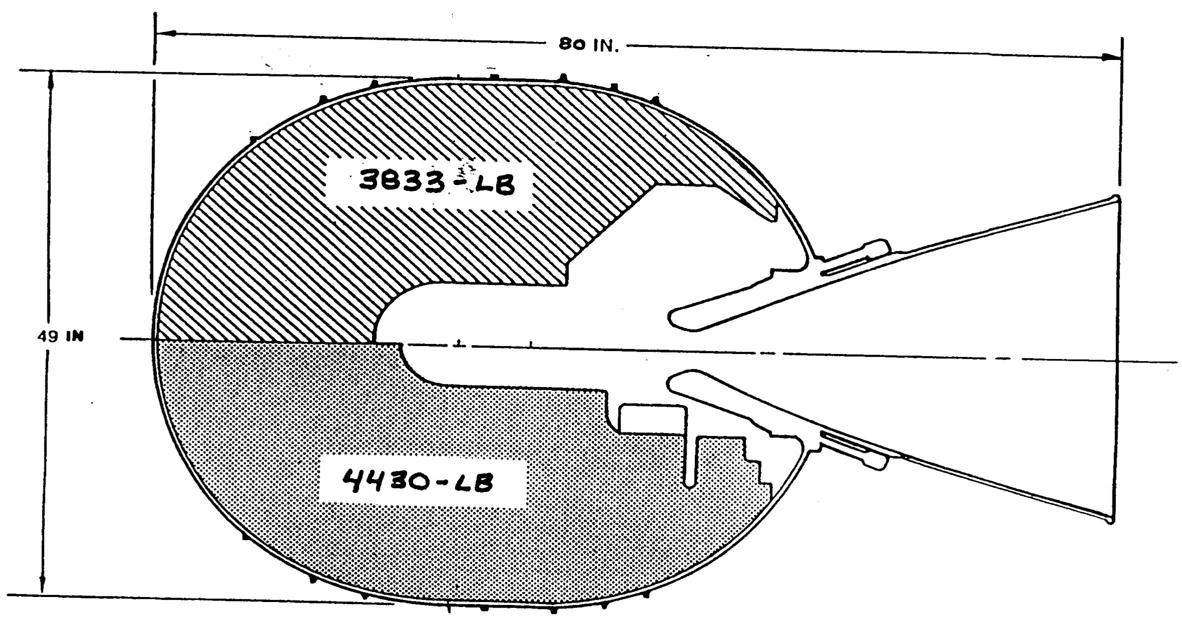
- Performance capability is estimated at 708 kg for the required orbit.
  - Based on preliminary 732x velocity reserve study, a 478 lb (10.8%) offload of the Star 48B third, maximum ballast of ±10 lb
- Probability of command shutdown 99.7 percent.
- Star 48B motors exhibit coning instability during the last portion of the burn.
  - A nutation control system (NCS) was implemented to control coning.
  - System uses a single aft-facing hydrazine thruster and a rate gyro sensor.
  - The NCS system has been used 37 times without a failure.

COMPARISON OF STAR-48B PROPELLANT GRAIN CONFIGURATIONS

#96047MOM
9/16/96
3

McDonnell Douglas Aerospace - Space Transportation Division

This chart shows the qualified propellant loads of 3833-lb and 4430-lb. Intermediate loads are achievable and can be qualified by analysis.



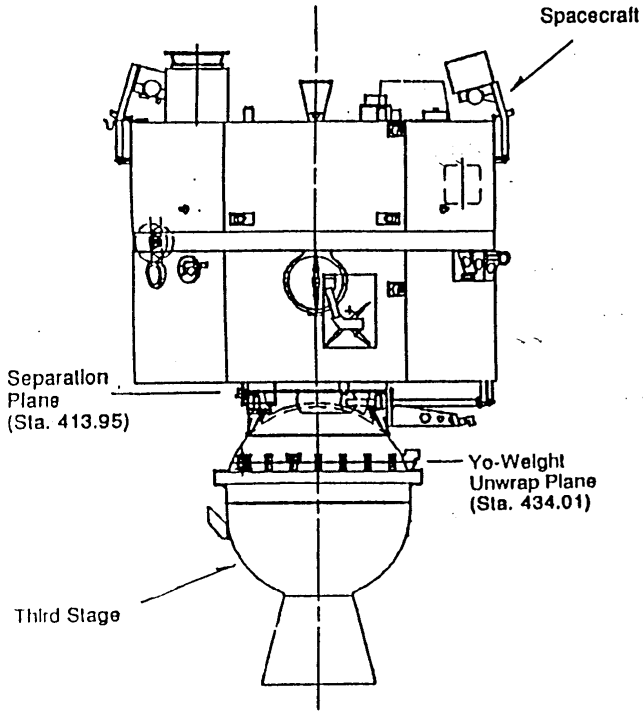
Despin System

- A yo-yo despin system is used to despin the third stage/spacecraft stack from a typical rate of 60 rpm to 0 ± 2.0 rpm.
- Time for yo-yo deployment is typically 3-5 sec.
- The yo-yo has been flown on 5 missions - all successful
- Two equal weights, sized to achieve the final spin rate, are attached to Kevlar cables wrapped about three times around the PAF.
- Weights are initially held in place by restraint lanyards which are severed by redundant cable cutters.
- Spacecraft separation is delayed by timer to allow dissipation of residual motor thrust.

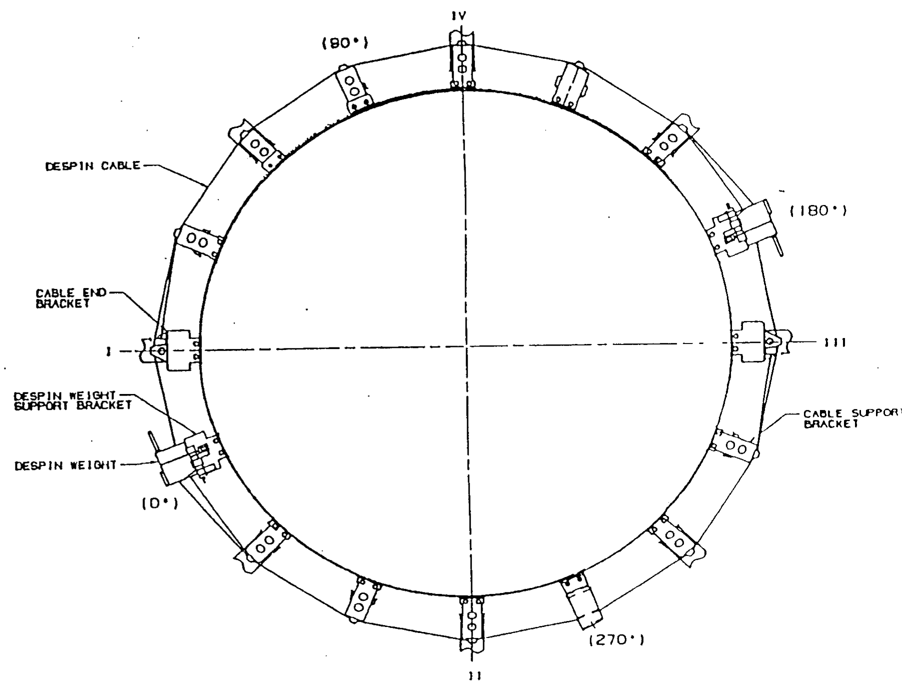
DESPIN SYSTEM MOUNTING ORIENTATION

M. Henderson
10/18/96

McDonnell Douglas Aerospace - Space Transportation Division

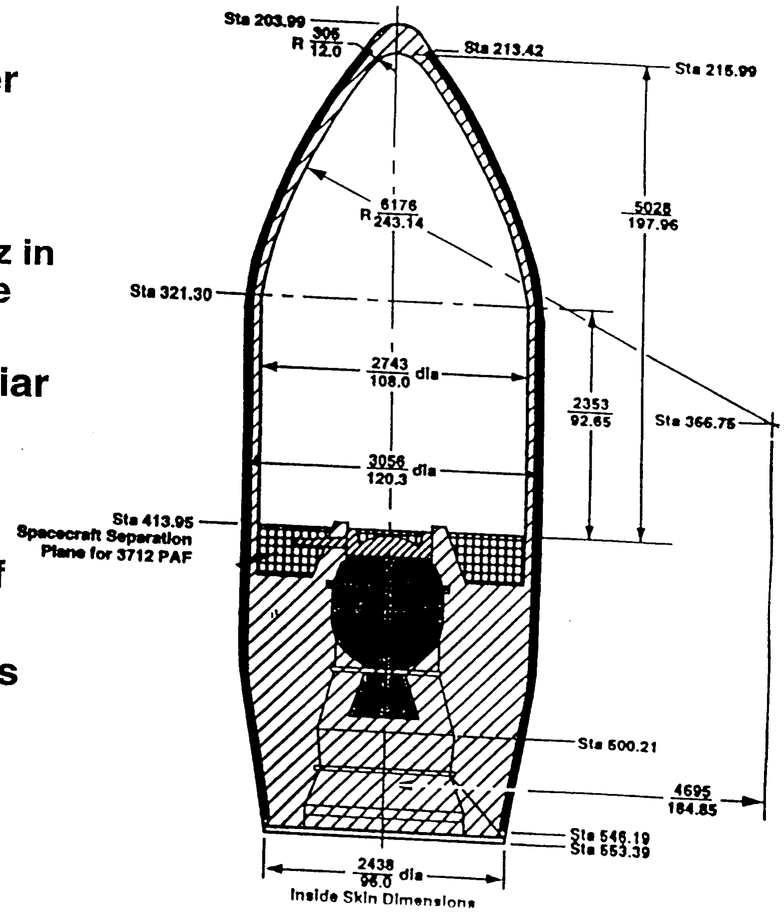


Side View of Spacecraft and Third Stage



10-Foot Fairing

- The 10-ft fairing has a static envelope with 108- inch diameter with 3-inch blankets in the cylindrical and nose sections.
  - Envelopes assume payload fundamental frequencies ≥ 35 Hz in the thrust axis and ≥ 15 Hz in the lateral axis.
- Two 2-ft diameter mission-peculiar doors are standard.
- Separation joint is non-contaminating.
- Class B GN_2 purge is standard, if required.
- Environmental instrumentation is required.
  - Temperature patch
  - Acoustic microphone

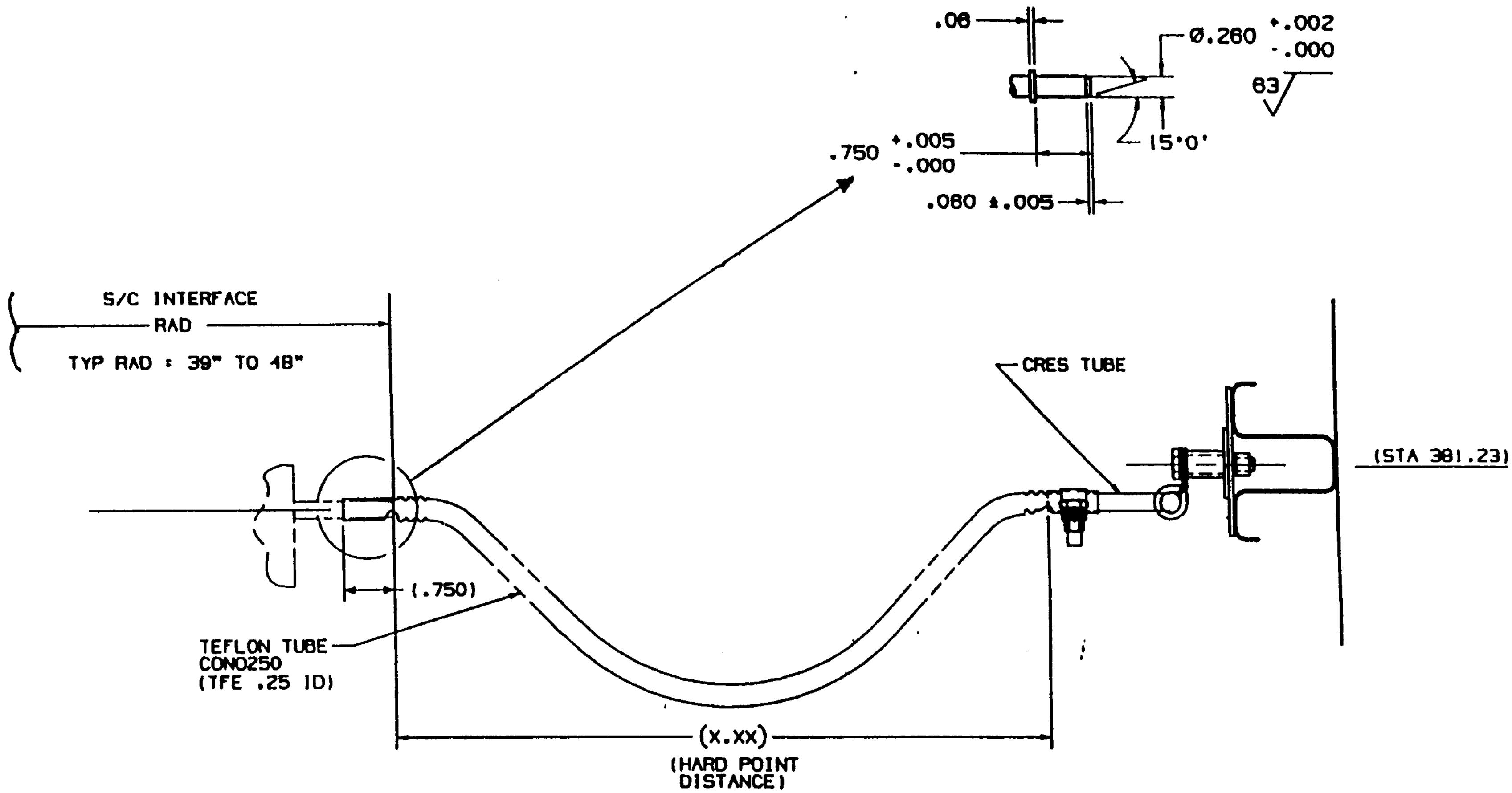


Fairing Separation

- Bisectors are joined by contamination-free linear piston/cylinder thrusting separation system that run longitudinally the full length of the fairing
- Bisectors are jettisoned by actuation of base separation nuts and by a detonating fuse in the thrusting joint cylinder rail cavity.
- A bellows assembly within each rail retains gases to prevent contamination

Purge System

- Supplies Nitrogen (Grade B standard) to spacecraft after fairing installation until lift-off
- S/C interface must be located in Quad I half of fairing
  - S/C purge port to be within 5 degrees of Quad I centerline and parallel to Quad I
  - No surrounding s/c intrusions within a 30 degree half cone angle from the mated interface
- Tubing (CRES and Teflon)
  - 0.25” diameter


.06
Ø.280 +.002 -.000
63
15°0'
.750 +.005 -.000
.080 ±.005
S/C INTERFACE
RAD
TYP RAD : 39" TO 48"
CRES TUBE
(STA 381.23)
(.750)
TEFLON TUBE
CON0250
(TFE .25 ID)
(X.XX)
(HARD POINT
DISTANCE)

SECTION B-B

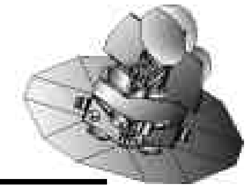
Launch Vehicle Review Process

- Pre-Ship Reviews
  - Held at the completion of all major element environmental and acceptance testing prior to delivery to the launch site
- Pre Vehicle On Stand Review
  - Post Delta Mission Check Out (DMCO) review of readiness to stack launch vehicle
- Launch Site Readiness Review
  - Held prior to upper stage/spacecraft erection and mate
  - Supplemented by a vehicle/pad walkdown by both MDA and NASA

Launch Vehicle Review Process

- Mission Readiness Review
  - To Code 400, Code 100 and NASA HQ
  - Both launch vehicle (OLS) and spacecraft readiness
- Launch Readiness Review
  - Chaired by Code 300
  - To assess the readiness of the launch vehicle and obtain concurrence for second stage fuel loading operations
- Flight Readiness Review
  - Chaired by launch management team
  - To assess readiness of the launch vehicle and obtain concurrence to proceed with the countdown.
  - Flight certification document sign-off by McDonnell Douglas, NASA and USAF

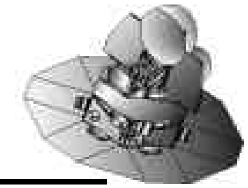
Operations Concept



- Requirements and Operations Concept
- Launch Requirements and Approach
- Ground Station Requirements, Coverage & Contact Schedules
- Link Margins
- Trajectory Analysis Results
- Maneuver & Station Keeping Approach

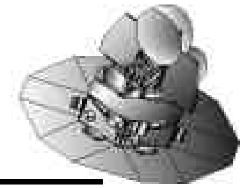
#	Title	Functional Requirement	Performance Requirements
3.5.1			Conduct the bulk of science observations in a 1 - 10 deg Lissajous orbit about the Sun/Earth second Lagrange point
5.5.1	Trajectory	The launch vehicle shall deliver the observatory to a transfer trajectory from which an observatory supplied propulsion system shall deliver the observatory to L2.	The launch vehicle shall provide a 708 kg throw weight to a 28.7 deg (ETR) inclination orbit with a C3 of -2.6 and a minimum perigee of 1000 km.
6.4.1	Delta-V Maneuvers	Provide the capability for trajectory correction and orbit maintenance.	At L2, Delta-V maneuvers shall be in concert with momentum maneuvers.
6.4.5			For all maneuvers except stationkeeping and momentum management maneuvers at L2, the observatory shall be oriented such that the thrust vector remains aligned with the velocity vector.
6.5.3	Delta-V Maneuver Predictability	The execution of delta-V maneuvers shall be sufficiently predictable to achieve the required mission trajectory within the propellant allotment.	Uncertainty due to ground system modeling errors shall be limited to 1%.
6.6	Delta-V Budget	Provide sufficient Delta-V budget for the life of the mission.	
6.6.1			Delta-V of 1 m/s shall be provided for thruster calibration.
6.6.2			Delta-V of 10 m/s shall be provided to accommodate a daily 20-minute launch window.
6.6.3			Delta-V of 60 m/s shall be provided for trajectory maneuvers.
6.6.4			Delta-V of 15 m/s shall be provided for final perigee maneuver correction.
6.6.5			Delta-V of 10 m/s shall be provided for a mid-course correction maneuver.
6.6.6			Delta-V of 4 m/s shall be provided for stationkeeping for each year of observing at L2.
6.7.3	Momentum Management	Provide for necessary momentum maintenance.	At L2, momentum maneuvers shall be limited to <= 4 per year, and shall not interrupt the observing mode for more than 3 (TBR) hours.

Mission Overview



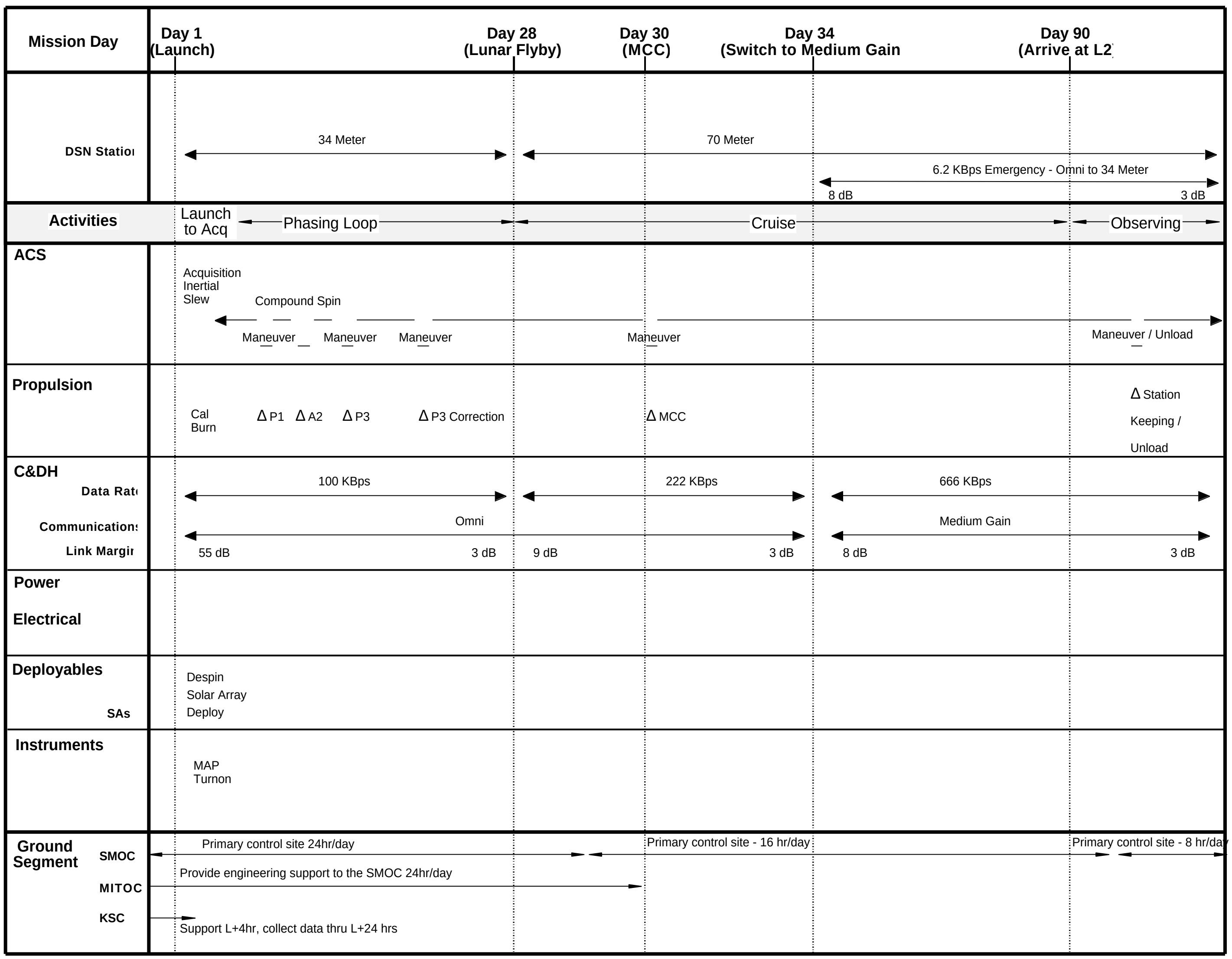
- Launch
  - Delta 7325 Launch into 185 x 250,000km orbit
- Separation and Acquisition
  - Acquire “Power Positive and Stable on the Sunline” Attitude
- Phasing Loops
  - Compound Spin except during Maneuvers
  - Spacecraft Propulsion system provides 60 m/s to achieve Lunar Gravity Assist
    - correct Launch Vehicle insertion errors
    - Allow approximately 3 weeks of launch opportunities each Lunar Month
  - 10 m/s to allow ≈ 20 minute launch window per day
- Cruise
- Normal Operations
  - Store and Forward Science and Housekeeping Data
  - Single Stored command load per week for planned DSN contacts
  - Single 37 minute pass per day

Mission Timeline

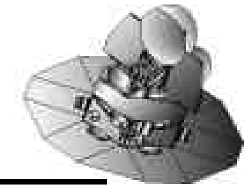


MAP SUMMARY TIMELINE Early Orbit Support

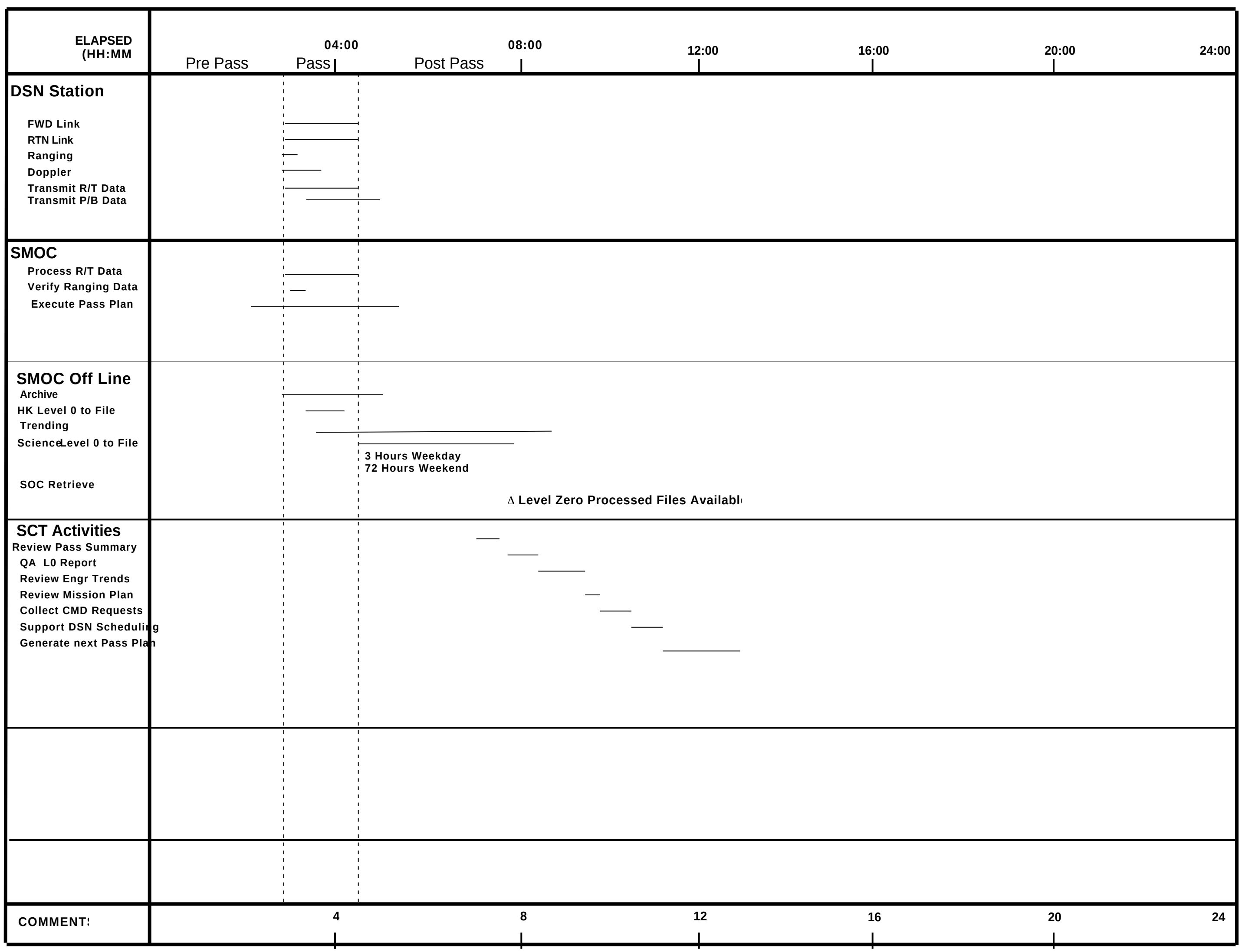
4/8/97



24 Hour Daily Timeline



MAP TIMELINE - Typical 24 Hr Day



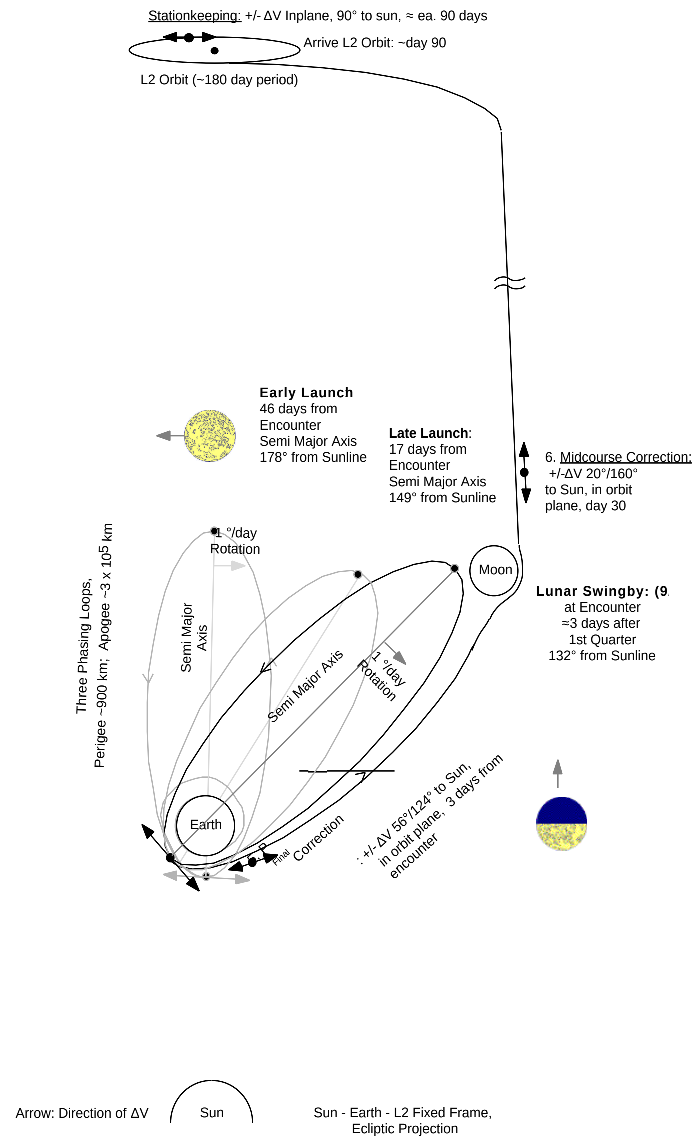
Trajectory Philosophy

- Utilize Lunar Gravity Assist to achieve L2 Orbit
- Lunar Gravity Assist occurs approximately ≈3.6 days before full moon (≈132° after New Moon)
- Launch Vehicle 3rd Stage Burn places MAP in a phasing loop with Apogee 60% of Lunar distance
- Select a fixed C3 of -2.6
  - maximizes Spacecraft mass into the parking orbit
  - provides ability to accommodate launch vehicle errors and multiple launch days

Trajectory Philosophy con't

- Utilize phasing loops to correct Launch Vehicle insertion errors and adjust for multiple Launch Opportunities
  - Onboard propulsion adjusts phasing loops
  - Approximate 3 week launch window during a lunar month. Three to four phasing loops to adjust the time between Launch and Lunar Encounter.
  - Correct +/- 15.6 m/s launch vehicle errors
- Utilize onboard propulsion to raise Apogee to Lunar distance to setup Lunar Gravity assist to L2
- Minimize the Delta V at the Final Perigee
  - Apogee raising is split between the final 2 Perigees
  - Errors at final perigee grow exponentially
- Utilize Apogee Maneuvers to Limit Perigee to >300 km

Trajectory Concept



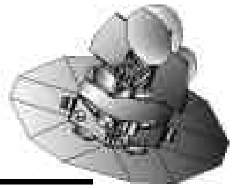
Launch Requirements

Altitude/	185 km circular parking orbit for 3rd stage burn,
Orbit	Fixed C3 of -2.6 +/-15 m/s based on 708 Kg spacecraft for 185 x 250,000 km orbit
Inclination	28.75°
RAAN and Argument of Perigee	Set for 3rd stage burn Latitude and Longitude at the point that “aims” the semi major axis at the moon where it will be during the lunar encounter, Maximize the angle between the orbit plane and the ecliptic plane to eliminate eclipses, 3rd stage burn opportunity between L+820 and L+6220 sec
Launch Window	1 Launch opportunity per day ≈ 20 minute limited by ≈ 10 m/s fuel budget for day of launch, approximately 3 weeks per lunar month, Lunar encounters October to Februrary (launches End of August to end of January)
Coast Attitude	Control Coast Attitude for Sun normal to solar array at slow ≈ 0.5 °/sec roll
Sep Attitude	Set by third stage burn attitude
Sep Rates	0 +/-2 RPM along spin axis, 0 +/-2 °/sec transverse tip off rate
Communications	32 KBps Real Time Downlink at separation to DSN or 2 KBps Real Time Downlink to TDRS, Command within 30 minutes of separation

Launch Sequence Requirements

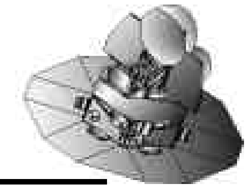
1. Wheels Off at Launch, turned on by Mongoose detecting separation with backup by a timer running in the PSE RSN software set to execute at separation.
2. Transmitter on 10 minutes prior to separation for either DSN or TDRS
3. Solar Array Deployment initiated by Fault Tolerant Separation signal. Housekeeping RSN hardware sequencer powers prime heater coils on both HOPS. Housekeeping RSN software sequencer powers redundant heater coils on both HOPS. Solar Array deployment complete within 5 minutes after separation.
4. Cat Bed heaters turned on by Mongoose timer 15 minutes prior to separation in case thrusters are required after solar array deployment. Mongoose will always wait at least 5 minutes after separation and for ground enable prior to allowing thruster firing.
5. ACS subsytem is allowed 35 minutes to acquire the Sun from separation for all modes including safehold to 2 sigma tip off. ACS uses wheels from 0 to 2 sigma tip off and thrusters after ground enable for tip off greater than 2 sigma.

Launch Sequence of Activities



Time	Event	PSE RSN	ACE RSN	HSKP RSN	Mongoose V
Prelaunch	S/C Configuration	1. Wheels Off	1. Sep signal holds Wheel Drive in Launch Mode (ACE S/W) 2. IRU On	1. Sep signal holds Launch Mode (S/A Deploy H/W Sequencer)	1. ACS S/W in Launch Mode waiting for ACE or Hskp RSN to detect Separation
L-15	Final Launch Mode Configuration	2. Start timer to turn Wheels on at Separation		2. Start timer to turn Transmitter on at Separation -10 minutes	2. Start MV Recorder 3. Start timer to turn Cat Bed on at Sep -20 and Transmitter on at Sep -10 minutes
L-5	Transition to Internal Power, 10 minute hold capability, Final "Go" for Launch	3. Go to internal power, SAS Off 4. Start Battery Discharging			
L+00:00:00	Lift off				
L+00:13:40	At Coast Attitude, start 0.5°/sec barbeque roll	Start Battery Charging			
L+00:13:40	Approx Sunset	Start Battery Discharging (40 min Max)			
L+00:53:00	Approx Sunrise	Start Battery Charging			
L+01:08:00 S-00:15:00	Cat Bed Heaters On		1. Command Cat Bed Heaters On		1. Send Command for Cat Bed Heaters On
L+01:13:00 S-00:10:00	Transmitter turn on			1. Transmitter cmded on	
S- 00:08:15	Stop Barbeque roll, orient to 3rd Stage burn attitude				
S- 00:06:15	3rd Stage Ignition				
S- 00:05:00	3rd Stage Burnout				
S-00:01:00	Wheels Commanded On	Command Wheels On from Internal Timer			Command Wheels On from Mongoose
S- 00:00:05	Yo Yo Despin				
L+01:23:00 S+00:00:00	**S/C Separation**		1. Sep signal allows drive of wheels	1. Sep signal start prime H/W deploy sequence, Power prime HOPS heater coils on redundant actuators 40w for 5 min 2. S/W Backup, Power redund HOPS heater coils both actuators 5 min 40w for 5 min	1. ACS S/W detect sep, propagate sep attitude 2. Start backup deploy seq, Command HOPS on, allow thruster despin after 5 minutes 3. Start Wheel Despin CSS acq in "night" mode 4. If above .5 Wheel and rates >1 rpm prepare thruster unload
S+00:00:01	Start Deployment Actuator Heat			3. Start Actuator Heat see above (80 W for 5 minutes)	
S+00:01:10	S/A Deploy Starts (earliest)	Start Battery Discharging			
S+00:05:00	S/A Deploy Complete (latest worst case)		1. Deploy pots read deployed 2. CSS available		1. S/A deployed allows CSS acq 2. S/A deployed allows thruster despin
S+00:05:00	Earliest Thruster Despin is allowed				3. Timer allows thruster despin
S+00:35:00	CSS Acq Complete sunline <25°	Start Battery Charging			4. CSS acq complete

Ground Coverage Requirements



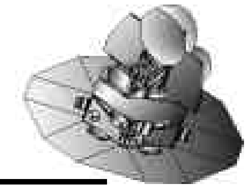
Phase	Downlink	Command	Tracking
Separation	• 10 min prior to separation to 1 hr after	• Within 30 minutes of separation to 1 hr after	• 8 hours two way doppler and ranging
Phasing Loop, Maneuvers	• Three hours contact per day	• Command within 30 minutes of burn start	• 4 hours tracking ending 8 hours prior to maneuver
	• At start, end, and during maneuvers	• Command within 30 minutes of burn end	• 8 hours after maneuver
L2 Normal Operations	• 37 minutes per day	• 37 minutes per day	• 5 minutes ranging, • 30 min doppler tracking

Operational Stations

DSN (Uplink, Downlink, Tracking)

TDRS (Downlink only at 2KBps, potential two way tracking if required for maneuvers)

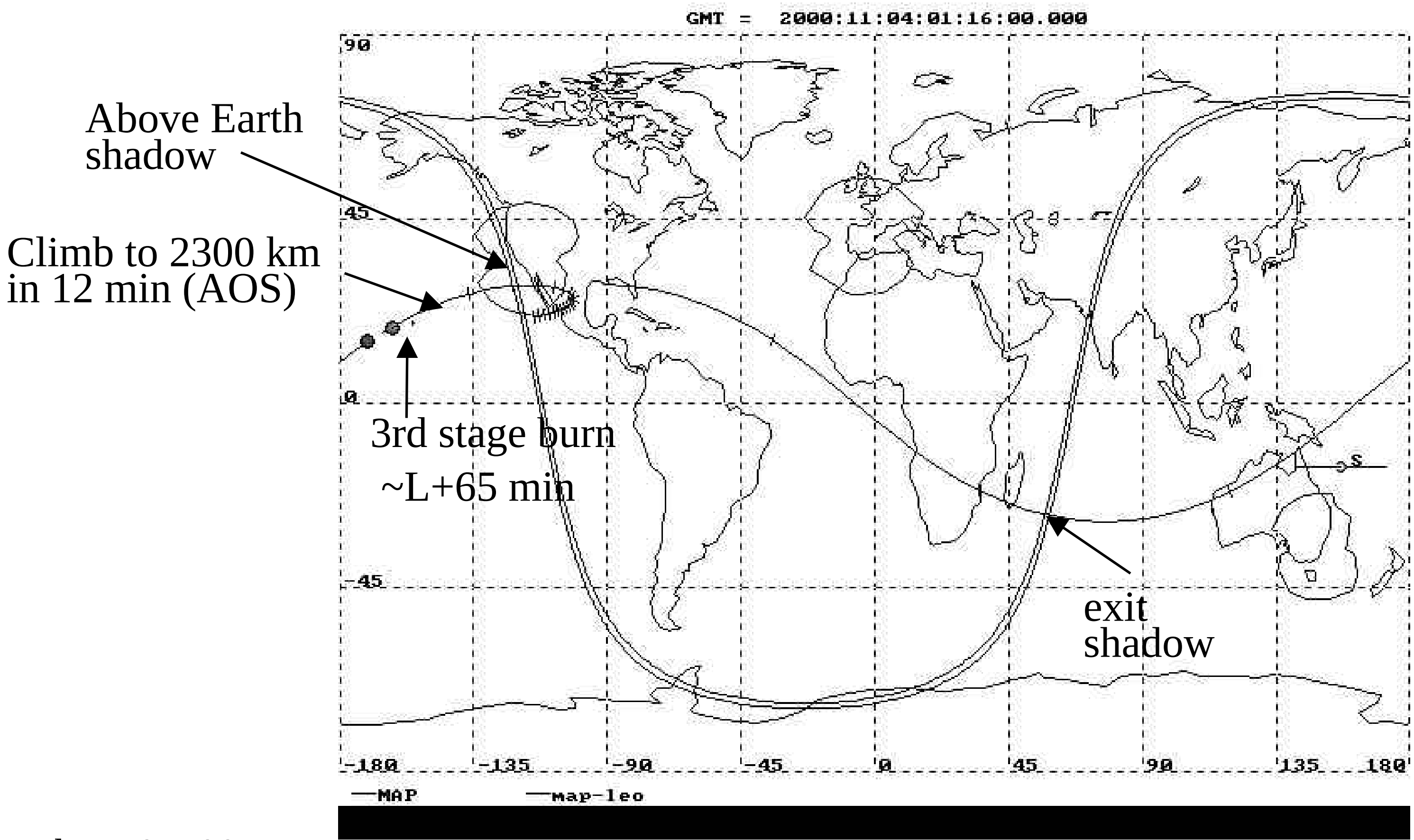
Tracking Requirements



Mission Phase	**Service**	**Data Type**	**Pass Frequency**	**Definitive OD Requirements (3 σ)**	**Predicted OD Requirements (3 σ)**
LEO (65 min)	None				
Transfer Trajectory Phase-nominal (20-45 days)	34-m or 70-m	Doppler, range	Three 1-hr passes/day*	Position: 5 km Velocity: 5 cm/s	Position: 50 km Velocity: 10 cm/s
Transfer Trajectory Phase-maneuvers & lunar gravity assist	34-m or 70-m	Doppler, range	Continuous M-12 h to M-8 h (4 h span) and M start through M+8 hr	Position: 5 km Velocity: 5 cm/s	Position: 50 km Velocity: 10 cm/s
Cruise (Gravity Assist to L2 Insertion) (~60 days)	70-m	Doppler, range	One 30-min pass/day*	Position: 5 km Velocity: 5 cm/s	Position: 50 km Velocity: 10 cm/s
Cruise-maneuvers	70-m	Doppler, range	Continuous M-12 h to M-8 h (4 h span) and M start through M+8 hr	Position: 10 km Velocity: 5 cm/s	Position: 50 km Velocity: 10 cm/s
L2-nominal (2 years)	70-m	Doppler, range	One 30 min pass/day*	Position: 10 km Velocity: 5 cm/s	Position: 50 km Velocity: 10 cm/s
L2-maneuvers	70-m	Doppler, range	Continuous M-12 hr to M-8 hr (4 hr span) and M start through M +8 hr	Position: 10 km Velocity: 5 cm/s	Position: 50 km Velocity: 10 cm/s

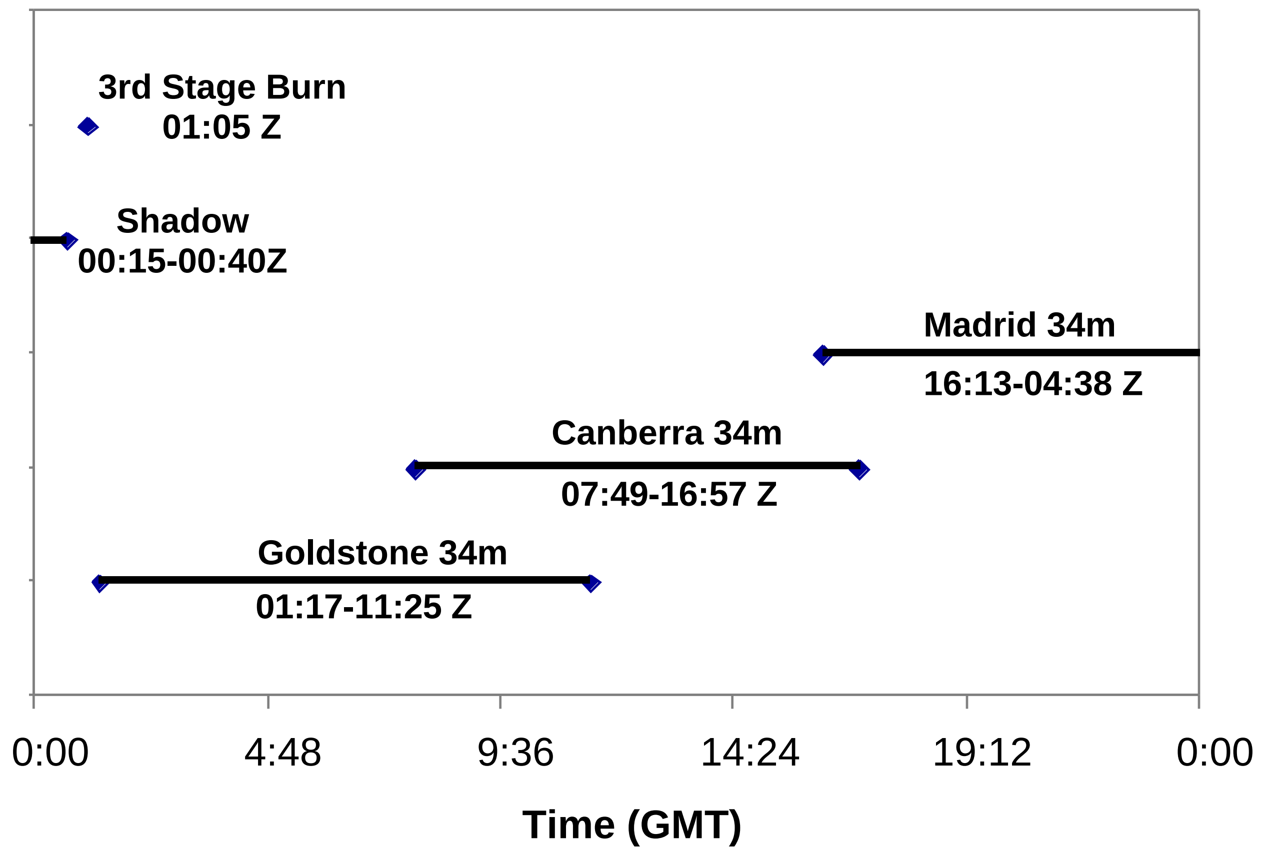
***prefer alternating N & S hemisphere DSN stations**

Early Orbit Ground Track



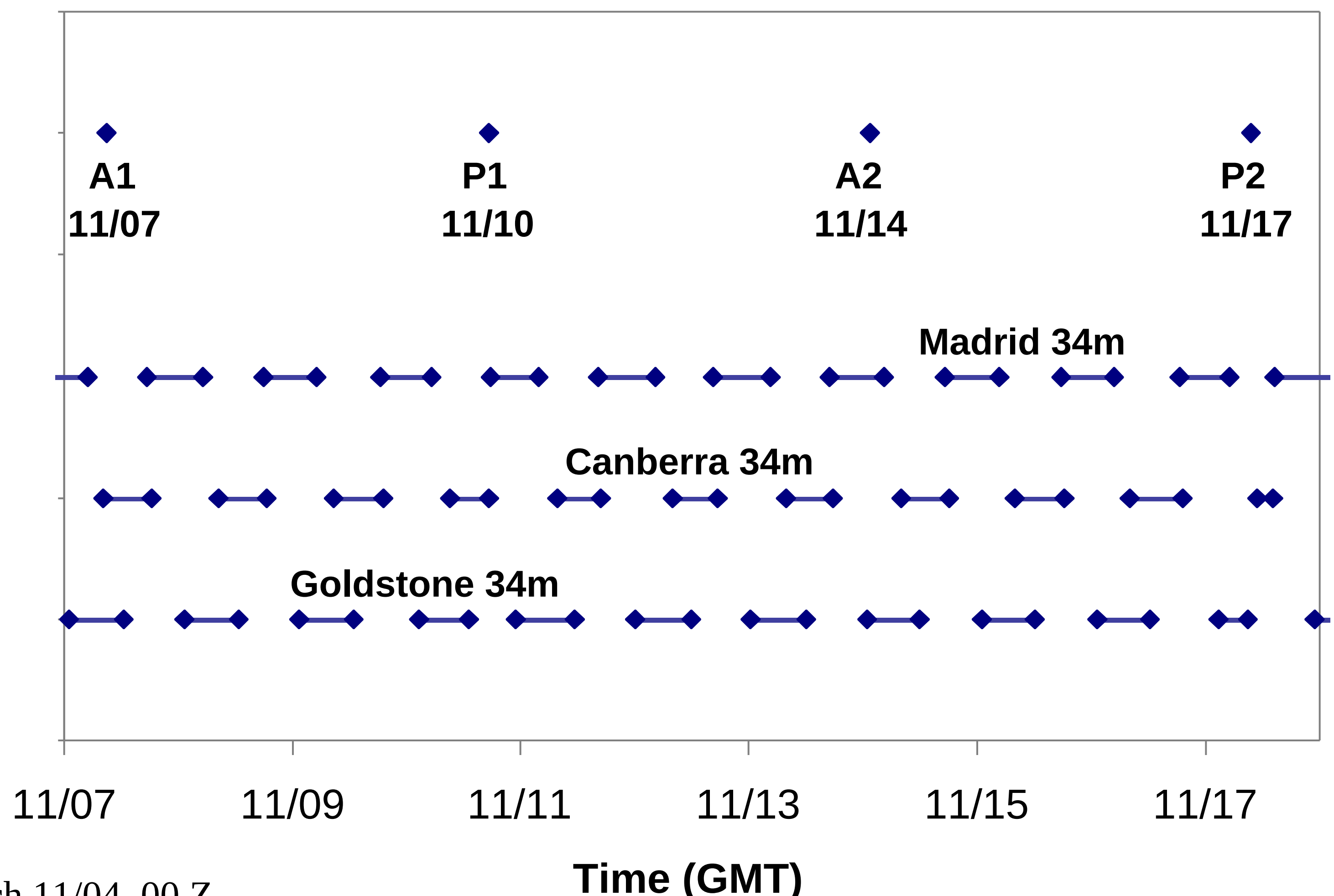
Launch 11/04 00 Z

Ground Station Coverage



Launch 11/04 00 Z

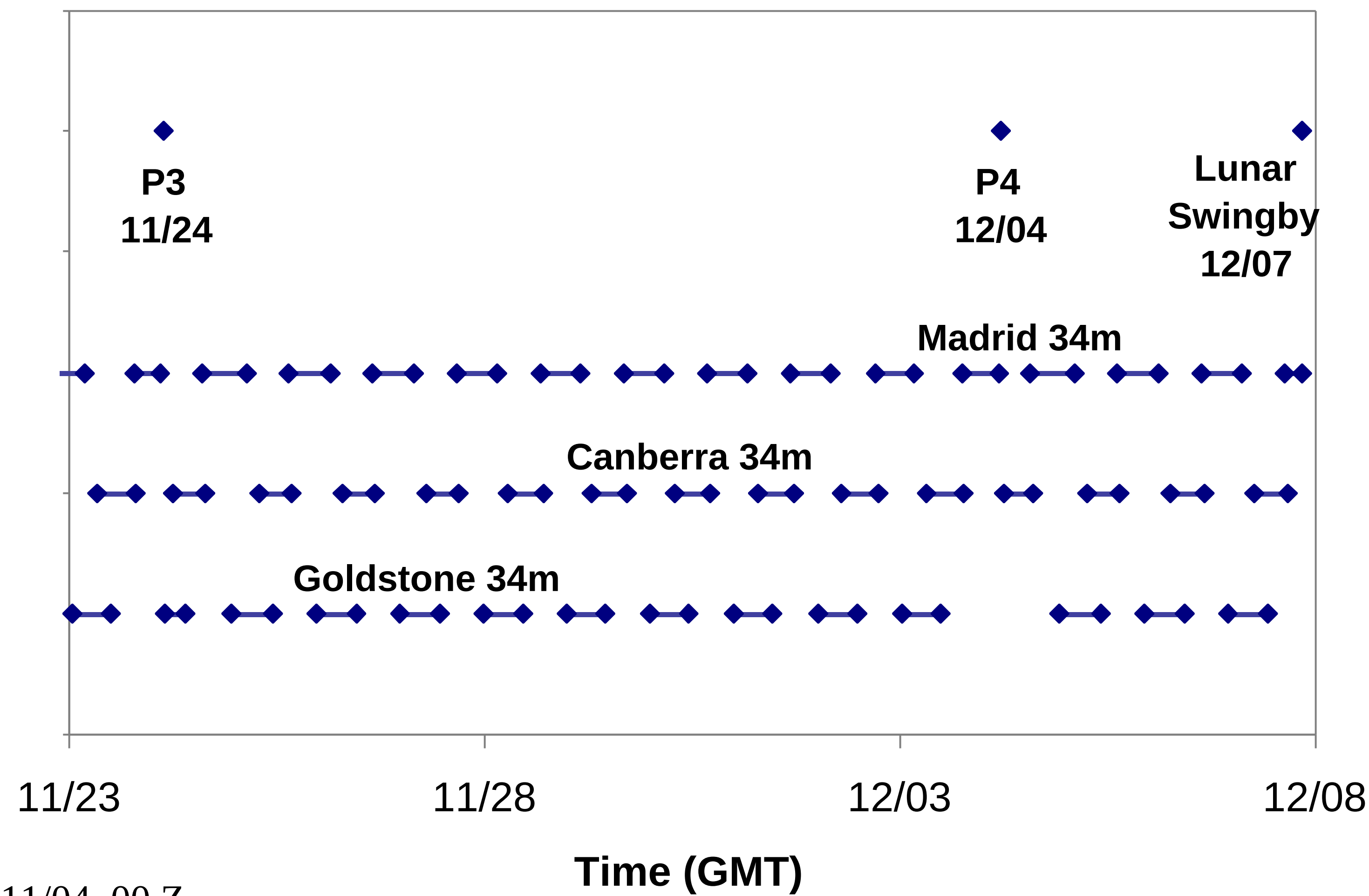
Ground Station Coverage



Launch 11/04 00 Z

Ground Station Coverage

Operations Concept



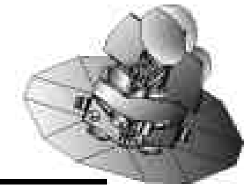
Launch 11/04 00 Z

Link Margin Summary

Comm. Link/Distance from Earth	Baseline Data Rate (kbps)	Coding	Link Margin (dB)	Comments
34BWG to Hemi Omni/ 1000 to 3.84E+5 km.	2.0	N/A	64 to 12.4	Primary uplink for phasing orbits to lunar swingby. Assumes a 1 kW transmitter
70 m. to Hemi Omni/ 3.84E+5 km. to 1.55E+6 km.	2.0	N/A	41 to 28.6	Primary uplink from lunar swingby to L_2 halo orbit
34BWG to Hemi Omni/ 1.55E+6 km.	2.0	N/A	19.4 to 7.3	Backup uplink from lunar swingby to L_2 halo orbit Assumes a 5 kW transmitter
Hemi Omni to 34BWG downlink/ 1000 to 3.84E+5 km.	100	Rate 1/2, K=7 + R/S	55 to 3.8	Primary downlink for phasing orbits to lunar swingby
Hemi Omni to 70 m./ 3.84E+5 to 7.5E+5 km.	222	Rate 1/4, K=15 + R/S	9.2 to 3.4	Primary downlink from lunar swingby to 6 days after lunar swingby
Med. Gain to 70 m./ 7.5E+5 to 1.55E+6 km.	666	Rate 1/4, K=15 + R/S	9.3 to 3.0	Primary downlink from 6 days after lunar swingby to L_2 halo orbit
Med. Gain to 34 m./ 1.55E+6 km.	120	Rate 1/4, K=15 + R/S	3.2	Backup downlink mode at L_2
Omni to 34 m./ 1.55E+6 km.	6.2	Rate 1/2, K=7 + R/S	3.8	Emergency downlink mode at L_2

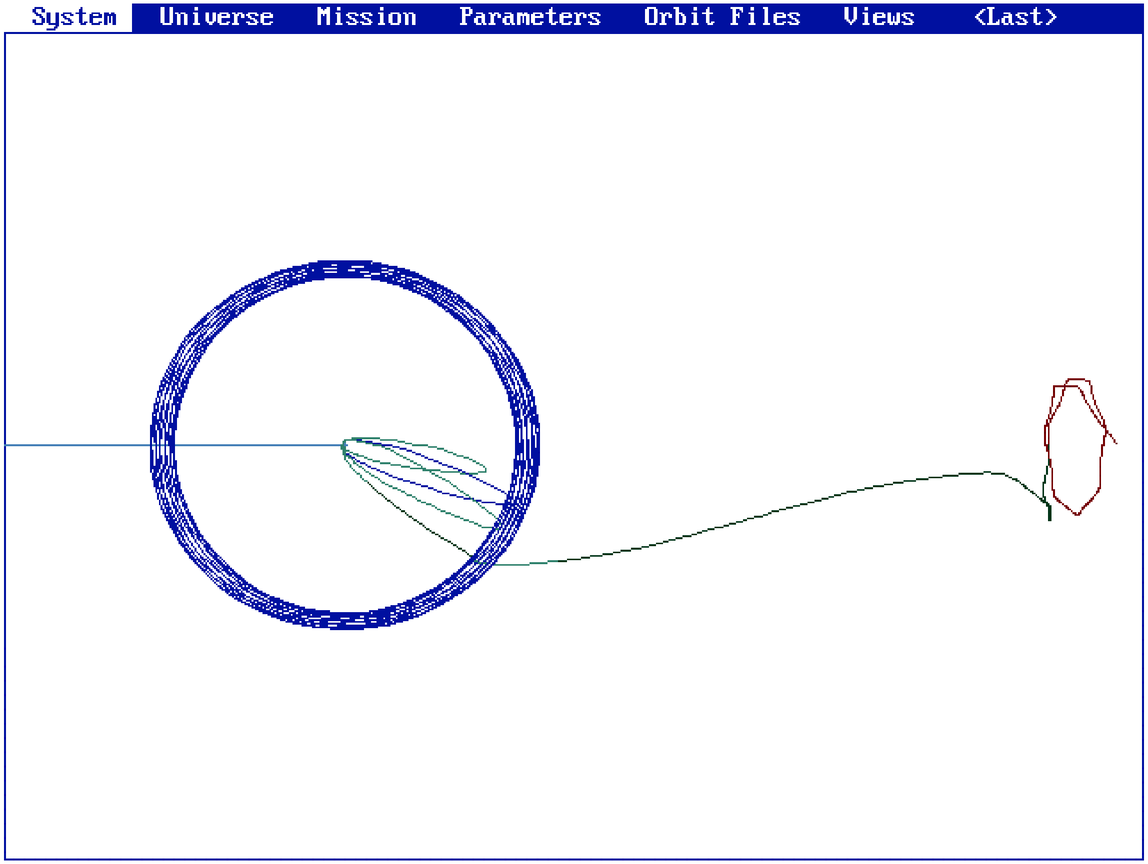
<u>Assumptions</u>:
- JPL's CCSDS Link Design Control Table used for all analyses.
- BER = 1E-8
- Mod Index = 1.50 rad-pk
- Ant. Pointing Loss = -0.2 dB
- DSN Block V Receiver

Trajectory Analysis Method

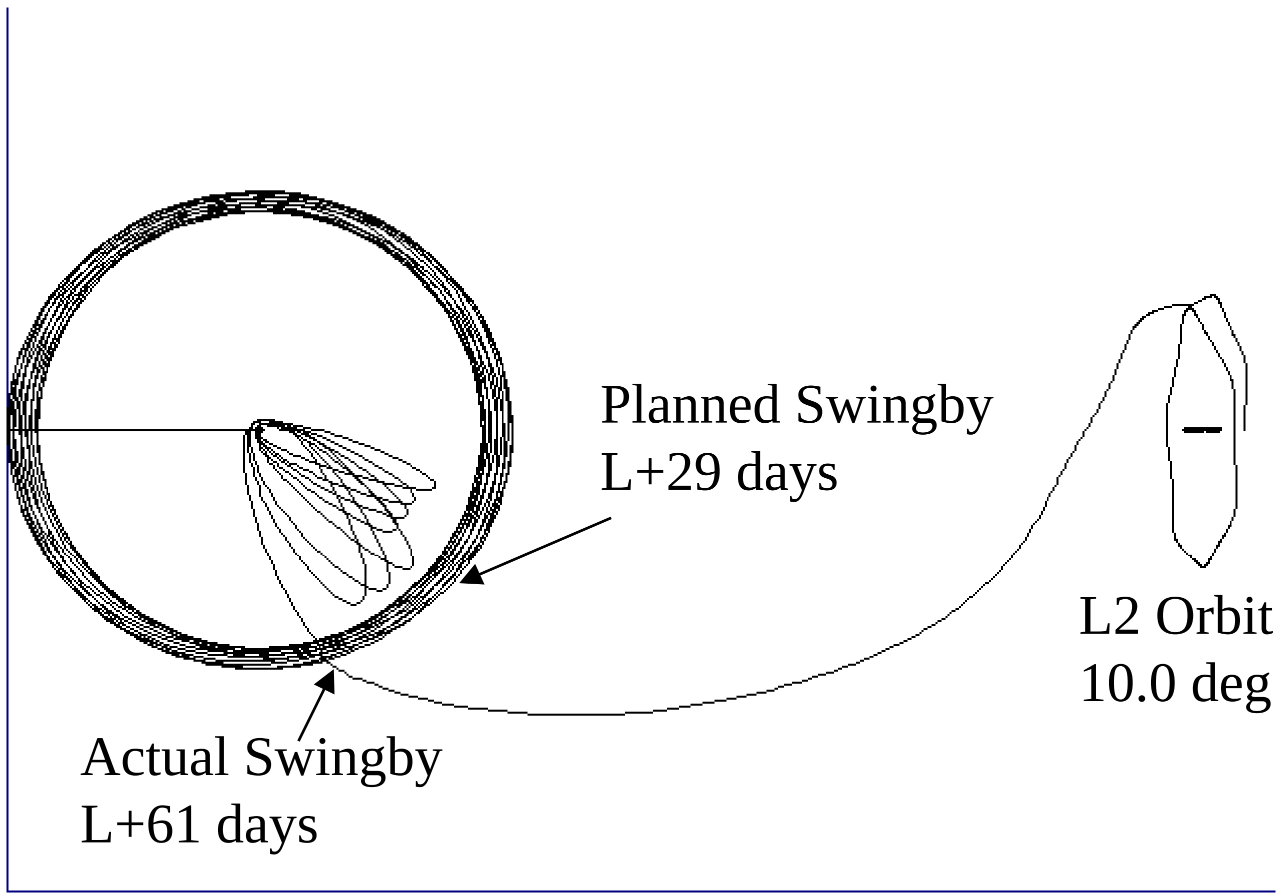


- Modeling 4 (Sun, Earth, Moon, S/C) body problem is "Chaotic"
  - Can not always predict results based on other cases, need to run many cases
- Select Lunar Swingby Date/Time
  - 3.6 days prior to Full Moon achieves acceptable L2 Orbit
  - allows potential for second chance encounter next lunar month
- Compute Launch & Coast Times for given date
  - Two opportunities every day, select one with highest resulting angle between orbit plane and ecliptic (Afternoon/Evening August to January)
- Compute 3 Trajectories using Swingby
  - Nominal: No LV error, C3 Energy=-2.6
  - 3 sigma Over/Under Burn 15.6 m/s
- Check Trajectory for:
  - Shadows, Perigee Altitude, L2 orbit size, P_{Final} burn size, Total Delta V
  - Iterate if Necessary
- Next Launch Day (and so on, and so on.....)

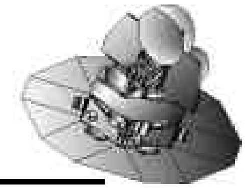
Analysis Results



Recovery From Missed ΔV



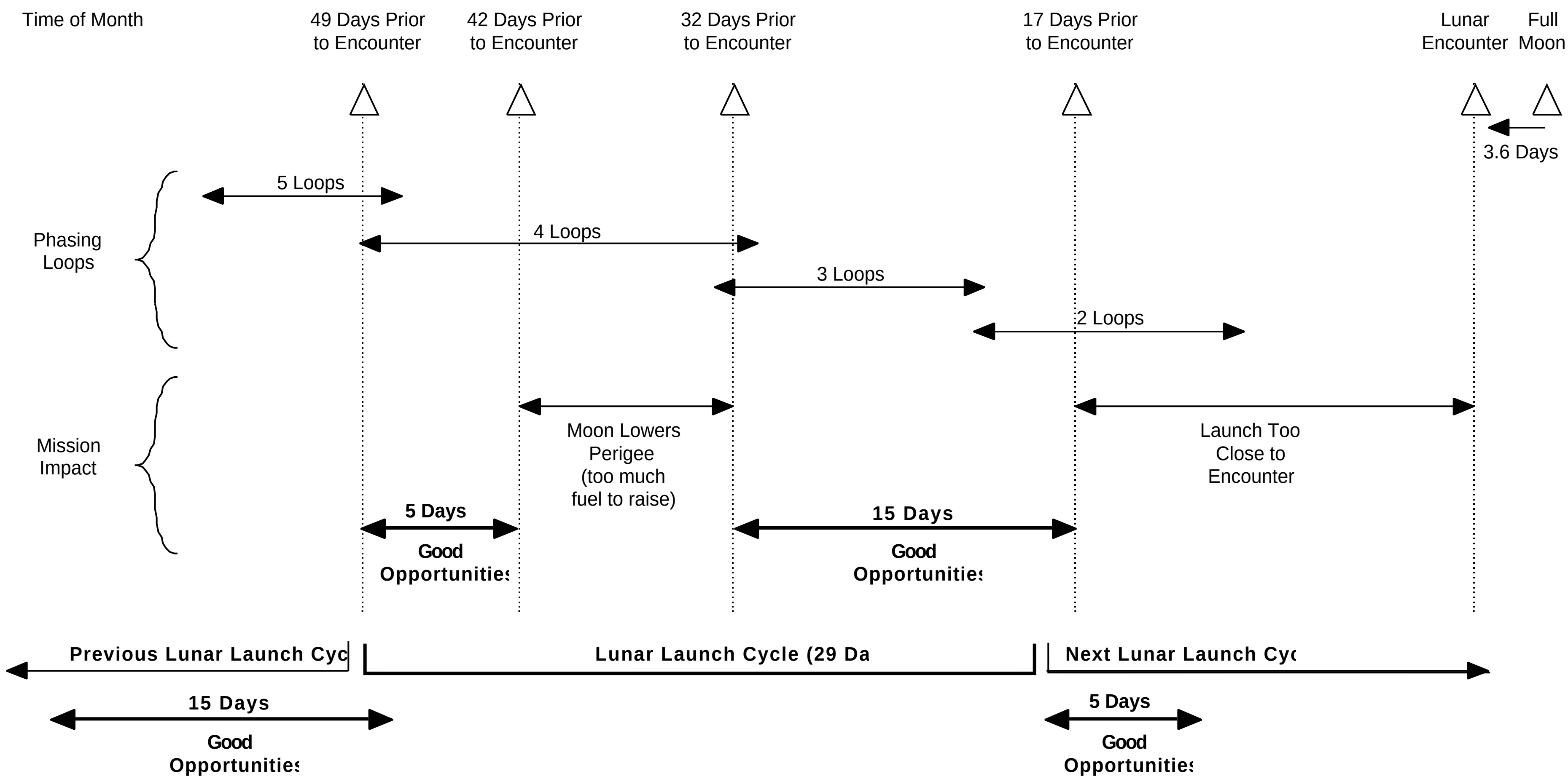
Summary of Analysis Results



- Acceptable Launch Opportunities Available
  - 17 to 31 and 43 to 48 days prior to Swingby (5 days)
  - 18 days out of 29 day Lunar Month Available, plus 2 days of overlap
- Lunar gravity negatively influences Perigee at certain times
  - Unstable from ≈32 to 42 days prior to Lunar Swingby
  - Small errors in ΔV may require big corrections
- Most fuel efficient location to correct:
  - timing errors is P1 or P2
  - energy errors is PF but PF-1 sometimes works
- Maximum Delta V is 45 m/s burn
- Afternoon Lanch Opportunity with 3rd stage burn during ascending portion of parking orbit
  - Avoids shadow during phasing loops
  - Launch time varies 22Z to 02Z August to February

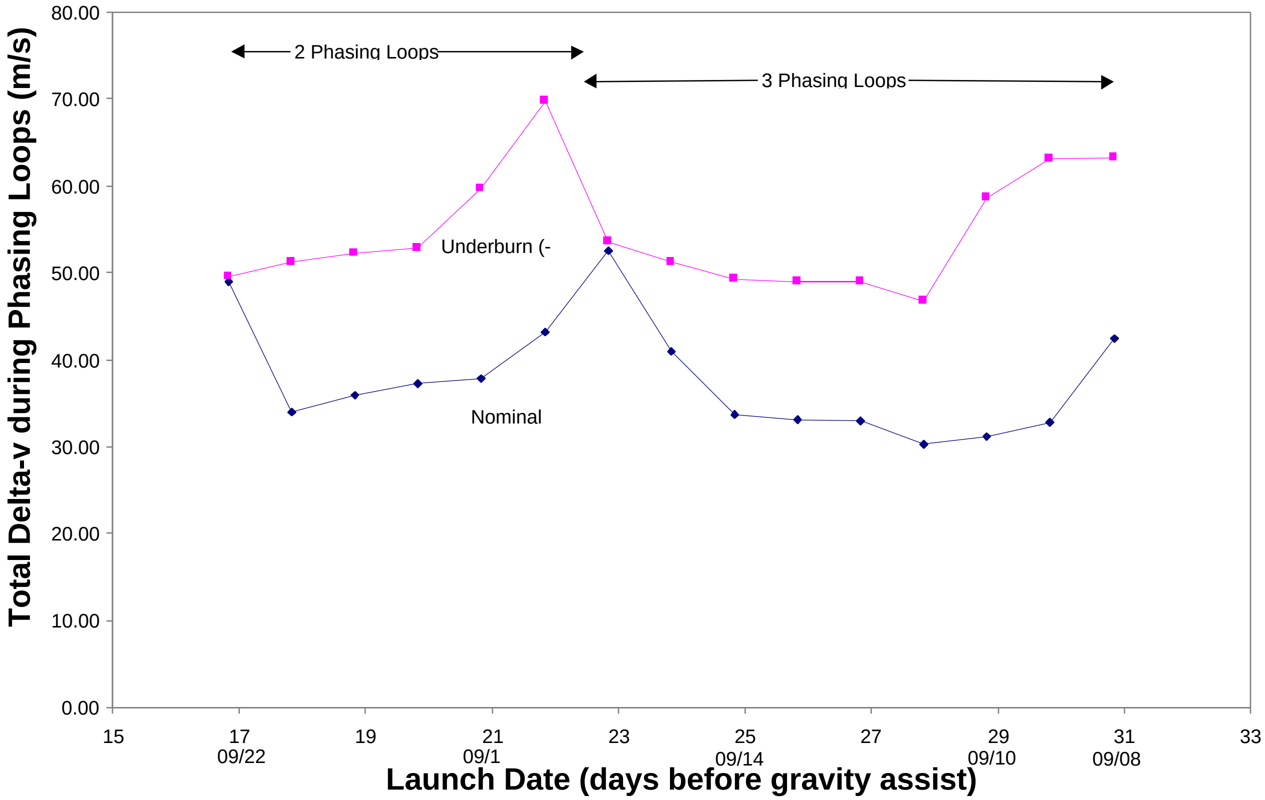
MAP Operations Concept

Monthly Launch Opportunitites



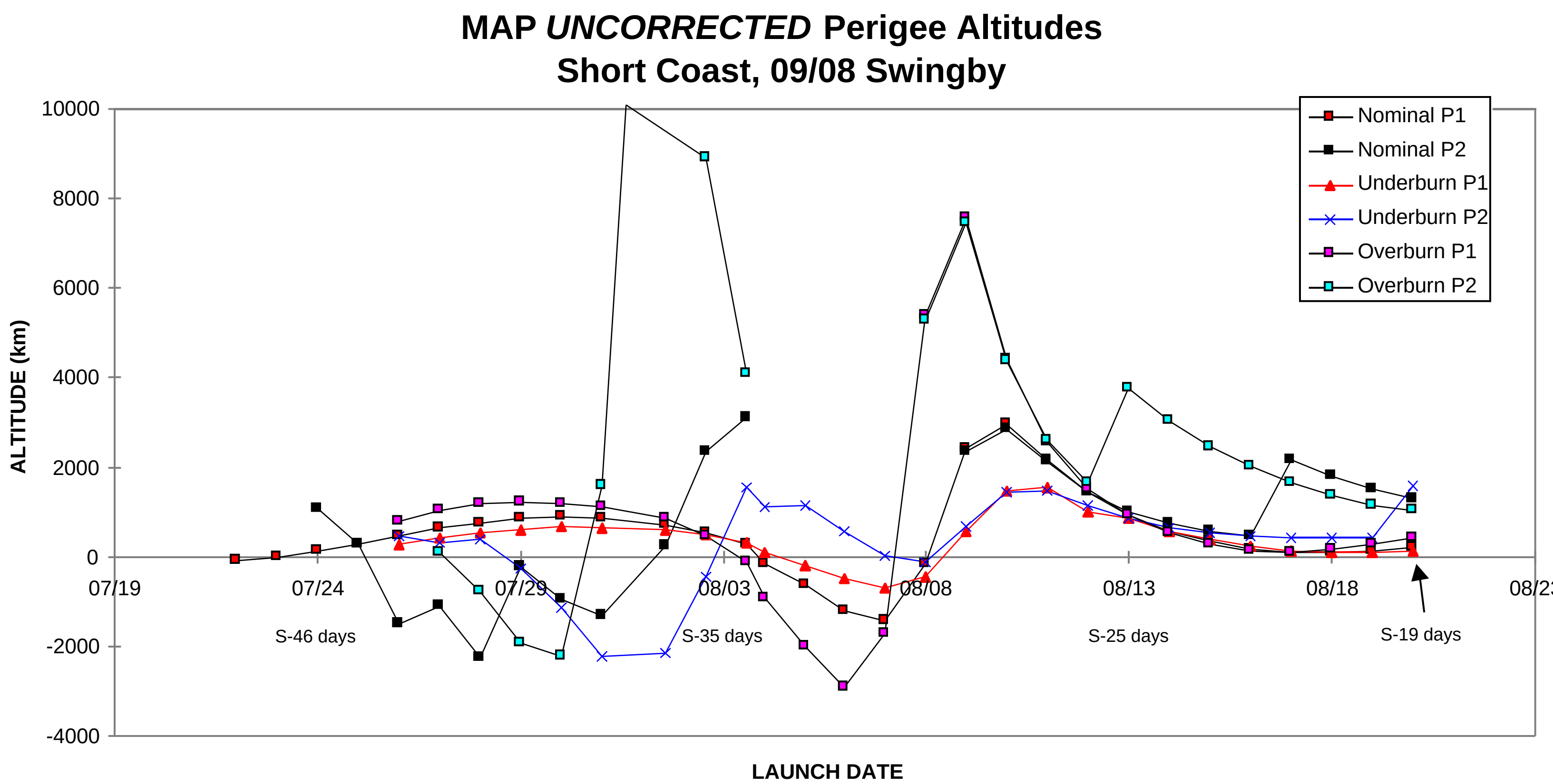
Analysis Results

Gravity Assist 10/09/2000
"Long Coast" solution; Launch ~22 Z

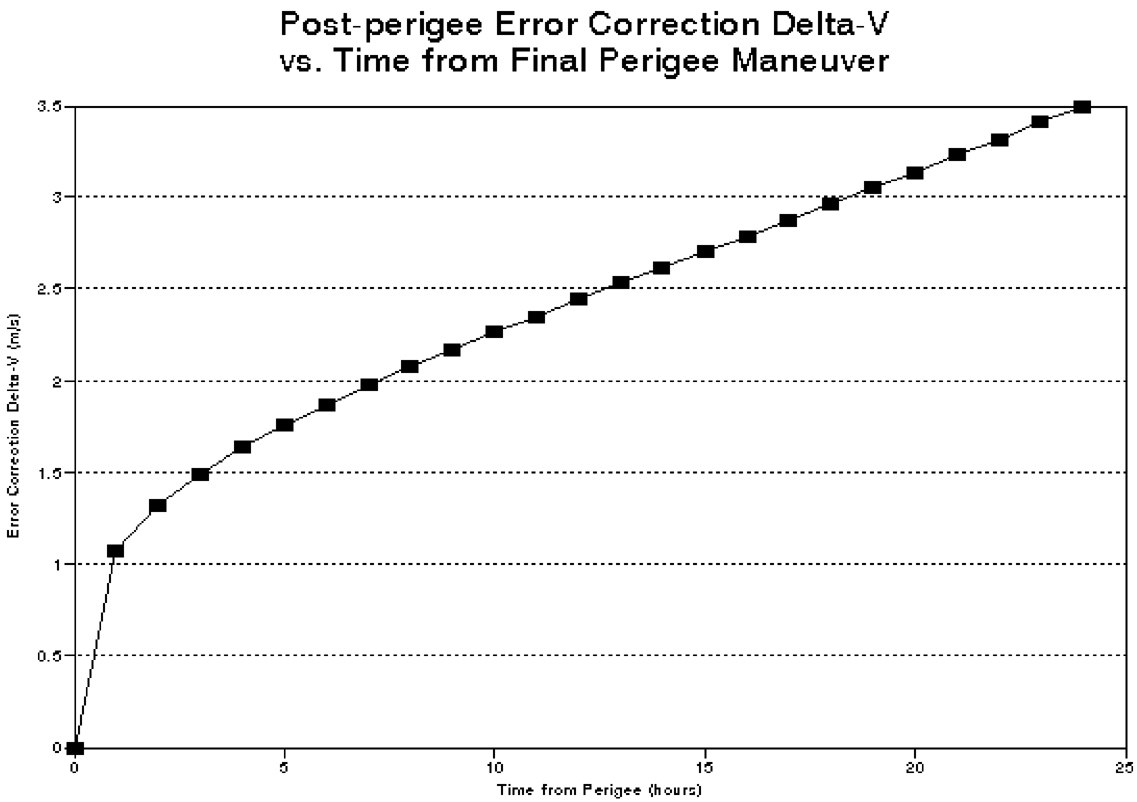


Summary of Perigee Effect

Operations Concept



Analysis Results

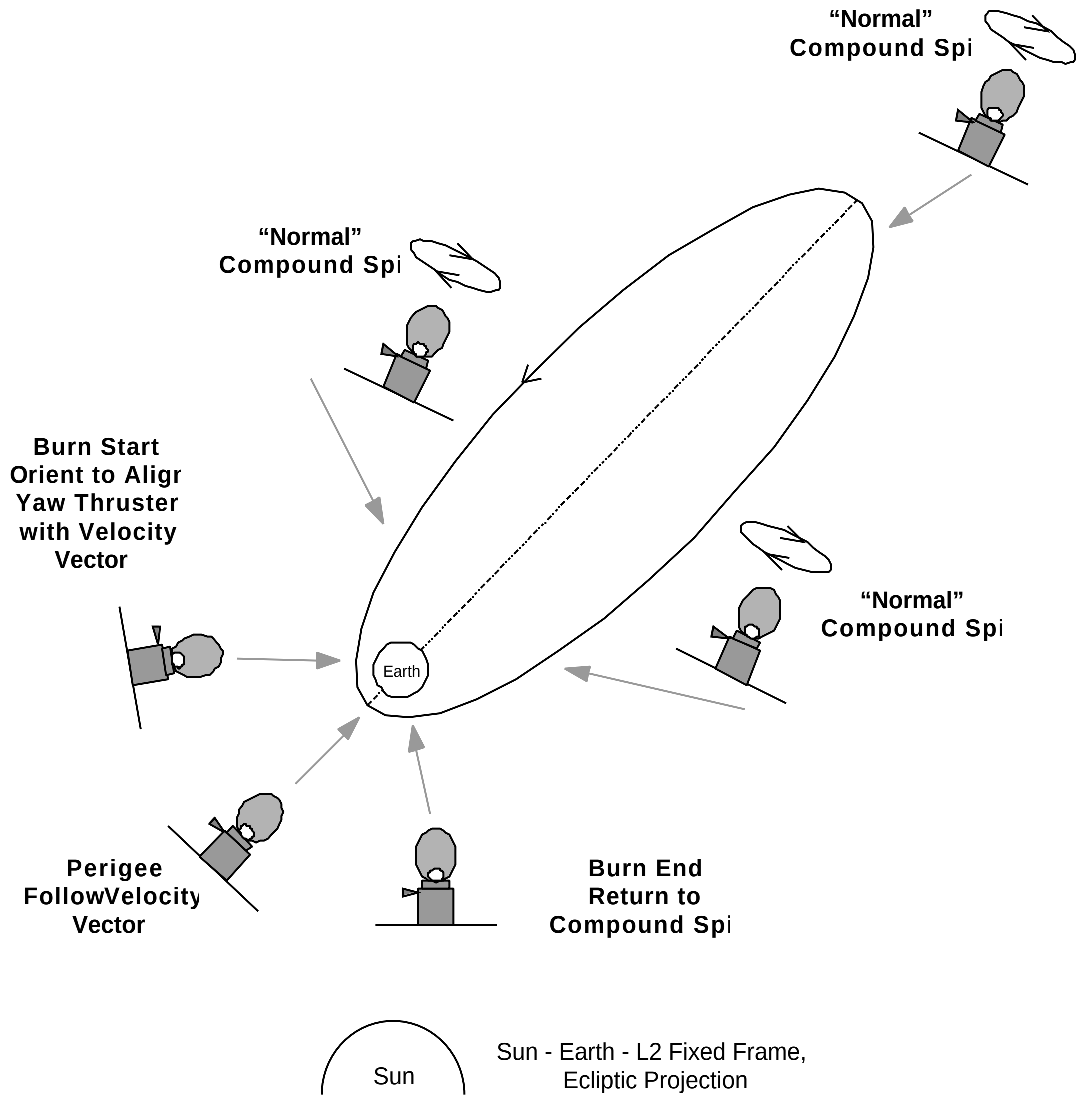


0.3 m/s error at Final Perigee

Maneuvers Approach

- Orient Yaw Thrusters along Velocity Vector within 5°
- Ground Uplink Quaternions for attitude profile
- Maneuvers along Velocity Vector at Apogee, Perigee, P_{final}, P_c
  - Apogee maneuvers maybe necessary to raise perigee altitude above 300 km minimum
- No L2 insertion maneuver
  - control through P_f and MCC

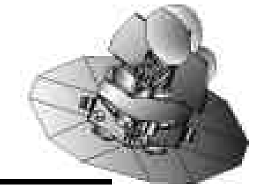
Maneuver Approach



Maneuver Operations

Event	**Time**	**Notes**
Collect Tracking	M-4 days to M-1 day	
OD solution	M-24 hr	
Prelim Maneuver Plan	M-16 hr	Impulse mnvr modeling
Deliver to MOC	M-15.5 hr	Dlvr to JPL NAV
Final Preburn Tracking for planning	M-12 hr to M-8 hr	Continuous range and Doppler tracking
OD solution	M-7 hr	Final preburn OD solution
Final Mnvr Plan	M-5 hr	
Meet with MOC	M-4.5 hr	Approval
Deliver to JPL NAV	M-4 hr	Predicted postburn vector or equivalent
Upload mnvr parms	M-3 hr	Start time, duration, table of attitude Quaternions

Maneuver Operations



Event	**Time**	**Notes**
ACS mnvr to burn attitude	M-20 min	Stop Compound Spin, Enter Inertial, Monitor RT
Maneuver	M	Duration up to 85 min Monitor RT tlm & track if avail
ACS Unload	M_{end} + 30 sec	Unload System Momentum
ACS mnvr to Sun ptg	M_{end} + 20 min	Return to Compound Spin, Monitor RT tlm
Prelim eval of mnvr	M + 1 hr	Prelim eval of mnvr based on tlm & 20 min Doppler data
OD solution	M + 30 min	Every 30 min until M+8 hr
Mnvr Evaluation/Prelim Plan for next Mnvr	M + 2 hr	Every hour until M+9 hr
Mnvr Eval	M + 9 hr	Inform MOC
Final Mnvr Eval, Prelim Mnvr plan	M + 1 day	Accelerated schedule for Pf correction < 18 hrs

Stationkeeping and Unloading

- Stationkeeping Expected / Planned every 3 months
  - Expected Delta V along sunline
  - 1 m/s
  - estimated from SOHO experience
- Unloading expected every 3 months
  - Unloading torque along S/C Z axis for pinwheel torques
  - Planned to minimize effects on stationkeeping

MAP DEEP SPACE NETWORK SUPPORT

AL BERMAN
MAP TMS MANAGER
JET PROPULSION LABORATORY
4800 OAK GROVE DRIVE, M/S 303-402
PASADENA, CALIFORNIA 91109-3817

PHONE: (818) 354-0072
FACSIMILE:
E-MAIL:

GARY K. NOREEN
TMOD FUTURE MISSIONS OFFICE
JET PROPULSION LABORATORY
4800 OAK GROVE DRIVE, M/S 303-402
PASADENA, CALIFORNIA 91109-3817

PHONE: (818) 354-2699
FACSIMILE: (818) 393-1692
E-MAIL: gary.k.noreen@jpl.nasa.gov
http://deepspace1.jpl.nasa.gov/advmiss

DSN AGENDA

- TMOD REORGANIZATION
- DSN OVERVIEW
- NETWORK DIAGRAM
- SIGNAL FLOW
- TELEMETRY SYSTEM
- SPECTRUM ISSUES
- RESOURCE ASSESSMENT

TMOD ORGANIZATION

JPL

DRAFT

900
TELECOMMUNICATIONS AND MISSION OPERATIONS DIRECTORATE
G. F. Squibb, Director
R. C. Coffin, Program Manager

900
R. P. Mathison, Chief Engineer
E. L. McKinley, Strategic and Process Planning
R. G. Polansky, Asst. Chief Engineer
M. J. Rodrigues, Asst. Program Manager
TBD, Manager, SOMO Data Services

910
BUSINESS OPERATIONS OFFICE
C. T. Stevens, Manager

TMOD PLANS AND COMMITMENTS OFFICE
R. B. Miller, Mgr.
D. G. Griffith, Deputy

- TMO SYSTEM ENGINEERING
- MOS SYSTEM ENGINEERING
- STRATEGY DEVELOPMENT
- DSN SCIENCE
- FUTURE MISSIONS PLANNING/COMMITMENT
- TMS MANAGERS

TMOD ENGINEERING OFFICE
J. I. Statman, Mgr.
J. C. Klose, Dep.

- DSN/AMMOS DEVEL.
- PROJ. GDS DEVEL.

TMOD OPERATIONS OFFICE
T. D. Linick, Mgr.
J. A. Wackley, Dep.

- DSN/AMMOS OPERATIONS
- FLIGHT MISSION OPS
- PROJECT MOS MGMT.
- CSOC MANAGEMENT
- RESOURCE ALLOCATION

TMOD TECHNOLOGY OFFICE
L. J. Deutsch, Mgr.
C. D. Edwards, Dep. (act.)

- FLT/GRND TECHNOLOGY DEVEL.
- DSN & AMMOS TECHNOLOGY DEVEL.

GALILEO PROJECT

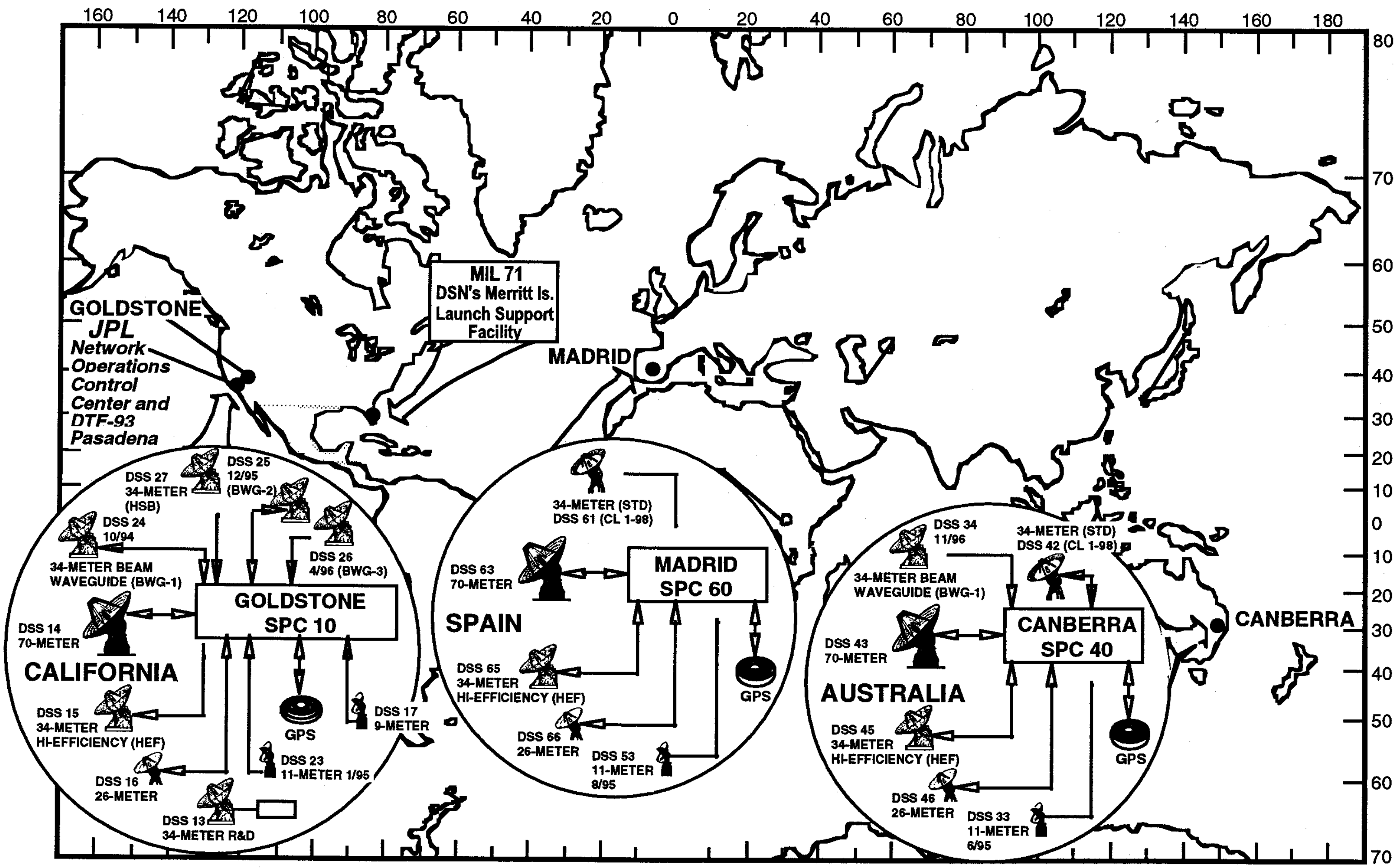
VOYAGER PROJECT

ULYSSES PROJECT

SPACE VLBI PROJECT

DSN OVERVIEW

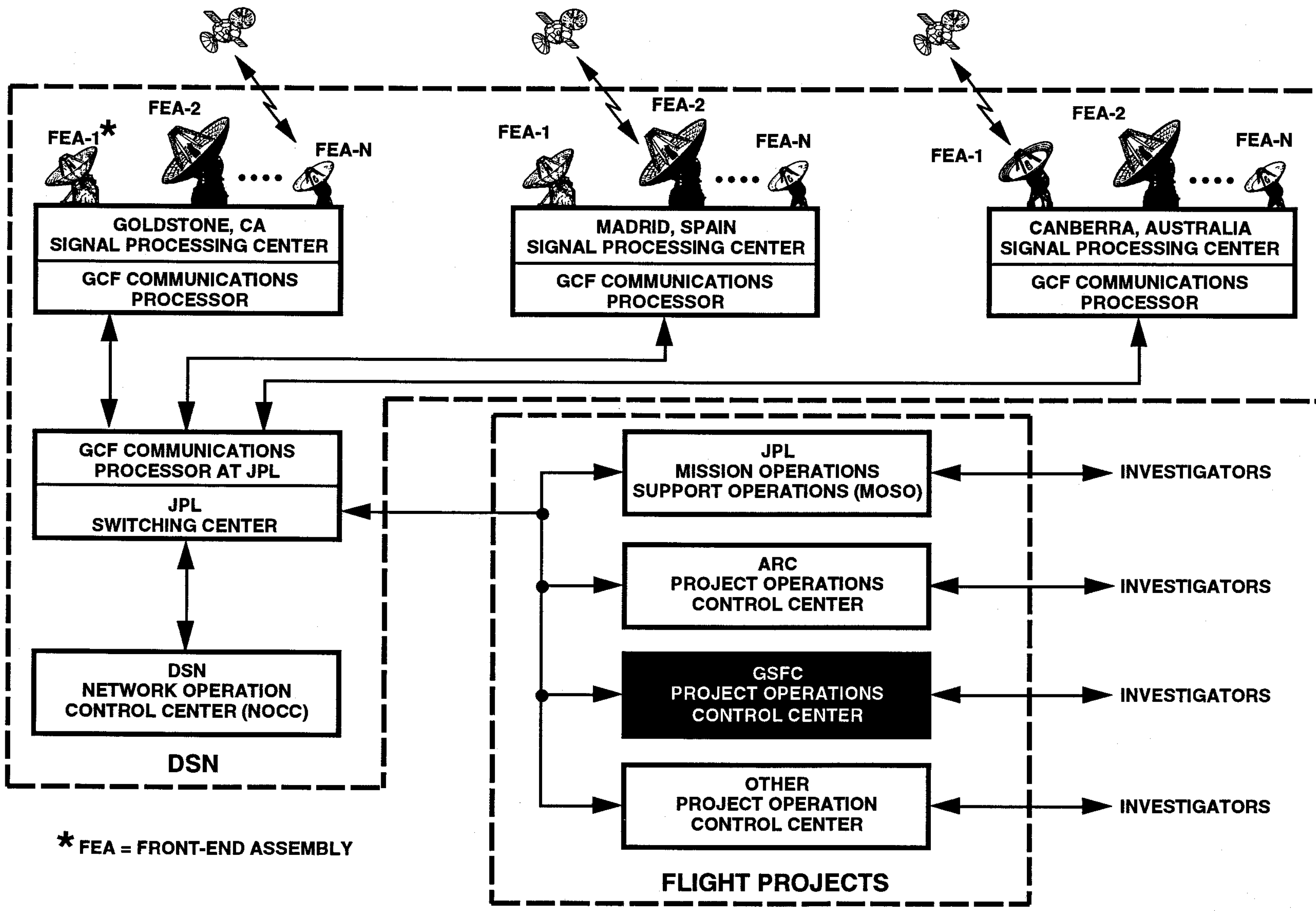
JPL



TELECOMMUNICATIONS AND MISSION OPERATIONS DIRECTORATE

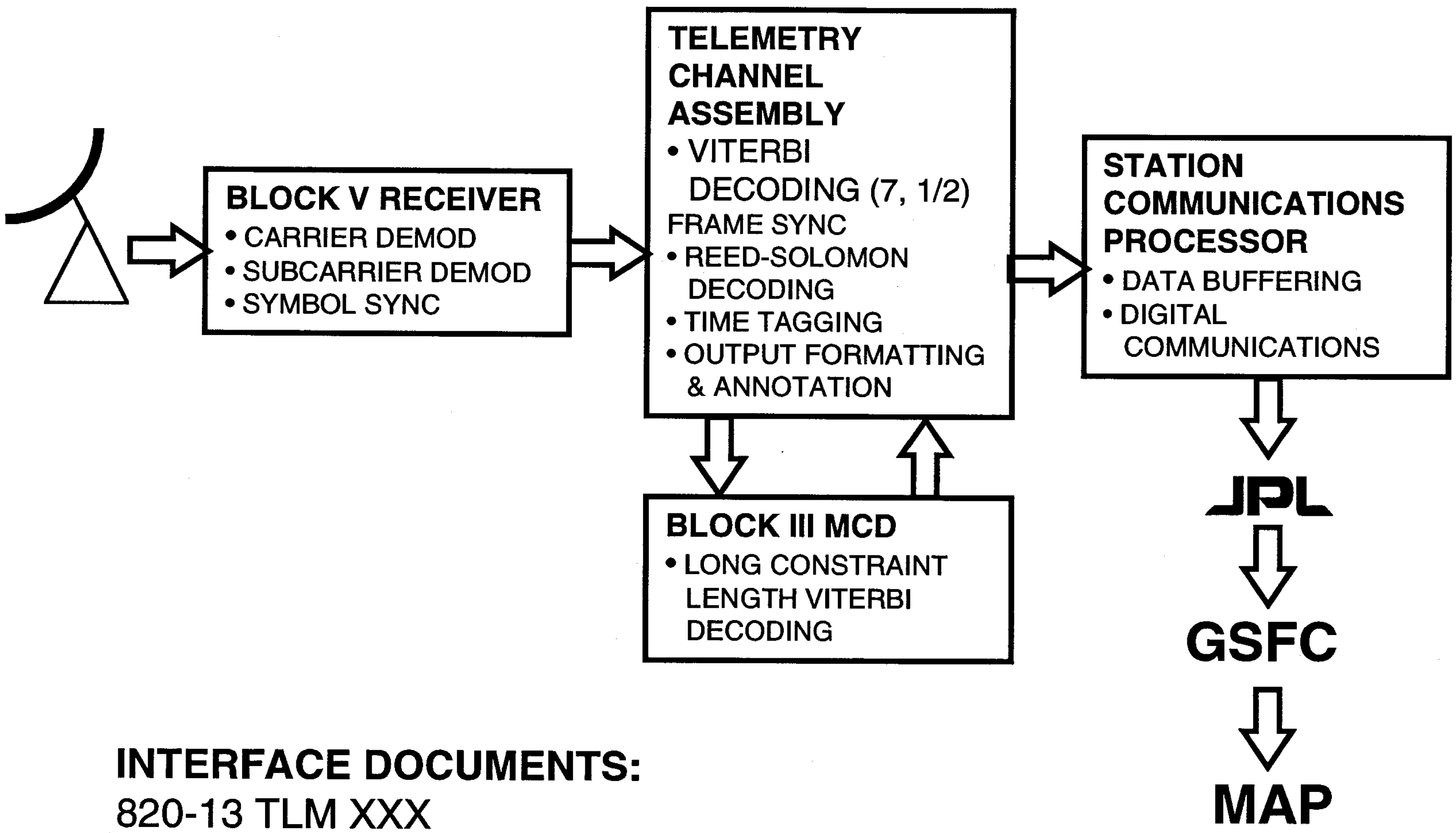
DSN NETWORK DIAGRAM

JPL



SIGNAL FLOW

JPL



INTERFACE DOCUMENTS:

820-13 TLM XXX

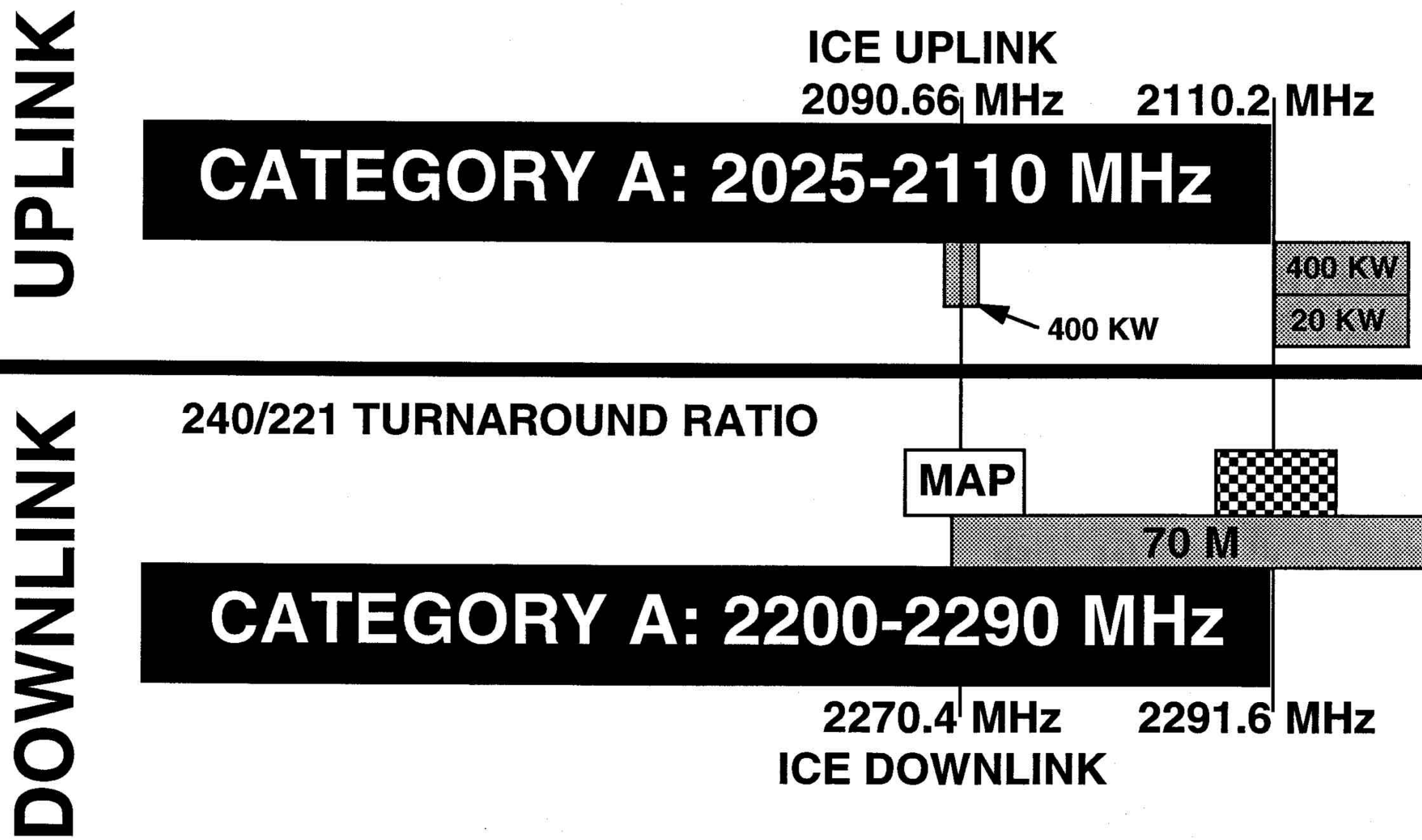
820-13 CMD XXX

GODDARD/JPL ICD MAP APPENDIX X

TELEMETRY SYSTEM

- DSN TELEMETRY SYSTEM SUPPORTS UP TO 2.2 MBPS, 6.6 MSPS
- BLOCK V RECEIVER
  - ENABLES DIRECT MOD ON CARRIER
  - PRIMARY DSN RECEIVER
- BLOCK III MCD
  - RATES 1/2, 1/3, 1/4 & 1/6
  - CONSTRAINT LENGTH UP TO 15
  - AVAILABLE AT ALL COMPLEXES
- MAP FULLY SUPPORTED
  - 666 KBPS TO 1 MBPS AT R=1/2 OR 1/4, K=15

SPECTRUM OVERVIEW



CATEGORY A ALLOCATION

- CATEGORY A S-BAND ALLOCATION
  - ITU DEFINITION: <2 MILLION Km
    - UPLINK: 2025-2110 MHz
    - DOWNLINK: 2200-2290 MHz
  - MAP: 1.5 MILLION Km
- 70 M SPECIFICATIONS
  - UPLINK: 2110.2-2117.6 MHz
  - DOWNLINK: 2270-2300 MHz

70 M TRANSMITTERS

- 20 KW
  - NARROWBAND
  - NO CATEGORY A CAPABILITY
- 400 KW
  - NARROWBAND
  - “HUMP” AT ICE FREQUENCY
  - OUTPUT POWER CAN BE CONTROLLED TO UNDER 100 KW

ICE FREQUENCIES

- INTERNATIONAL COMETARY EXPLORER
  - FORMERLY ISEE-3
  - REDIRECTED TO DEEP SPACE
  - 2090.66 Mz UPLINK WITH RANGING
  - 2270.4 MHz DOWNLINK
- MAP BW EXTENDS BELOW DSN SPEC
  - MEASURED 0.8 dB INCREASE IN SYSTEM NOISE TEMPERATURE AT 2266.4 MHz

MAP FREQUENCY VERIFICATION

- DTF-21 (JPL DEVELOPMENT & TEST FACILITY)
  - CHECK OUT ALL ELEMENTS EXCEPT ANTENNA FRONT END
  - USE ETU MODEL MAP TRANSPONDER WITH JPL TRANSMITTER
- 70 M TEST
  - SCHEDULE 70 M TIME
  - TEST THROUGH DIPLEXER & MASER
- NEW HEMT LOW NOISE AMPLIFIERS
  - WIDER BW
  - SIMILAR PERFORMANCE

RESOURCE ASSESSMENT

- BASED ON THE CURRENT MISSION SET, THE DSN WILL BE ABLE TO PROVIDE SUBSTANTIALLY ALL OF THE SUPPORT REQUESTED BY MAP.
- COMMITMENT OF DSN RESOURCES IS MADE THROUGH A JOINT USERS RESOURCE ALLOCATION PROCESS, NOT BY TMOD ITSELF. TO MAXIMIZE THE LIKELIHOOD THAT MAP RECEIVES ADEQUATE SUPPORT, MAP MUST BE AN ACTIVE PARTICIPANT IN THE RESOURCE ALLOCATION PROCESS.

MAP
ACE, C&DH & RF
Subsystems

Product Team Lead- John Ruffa

C&DH Lead- John Ruffa
ACE Lead- Mike Lin
RF Lead - Mike Powers

Agenda

- Subsystem Requirements
  - C&DH, ACE, and RF
- Remote Services Node (RSN)
  - Overview and Description
  - Implementation Approach
  - Test and Verification Flow
- MAC Functional Overview
  - Architecture Diagram
  - Development Status, Verification Flow
- RF Functional Overview
  - Transponder & Antenna Descriptions
- Conclusions

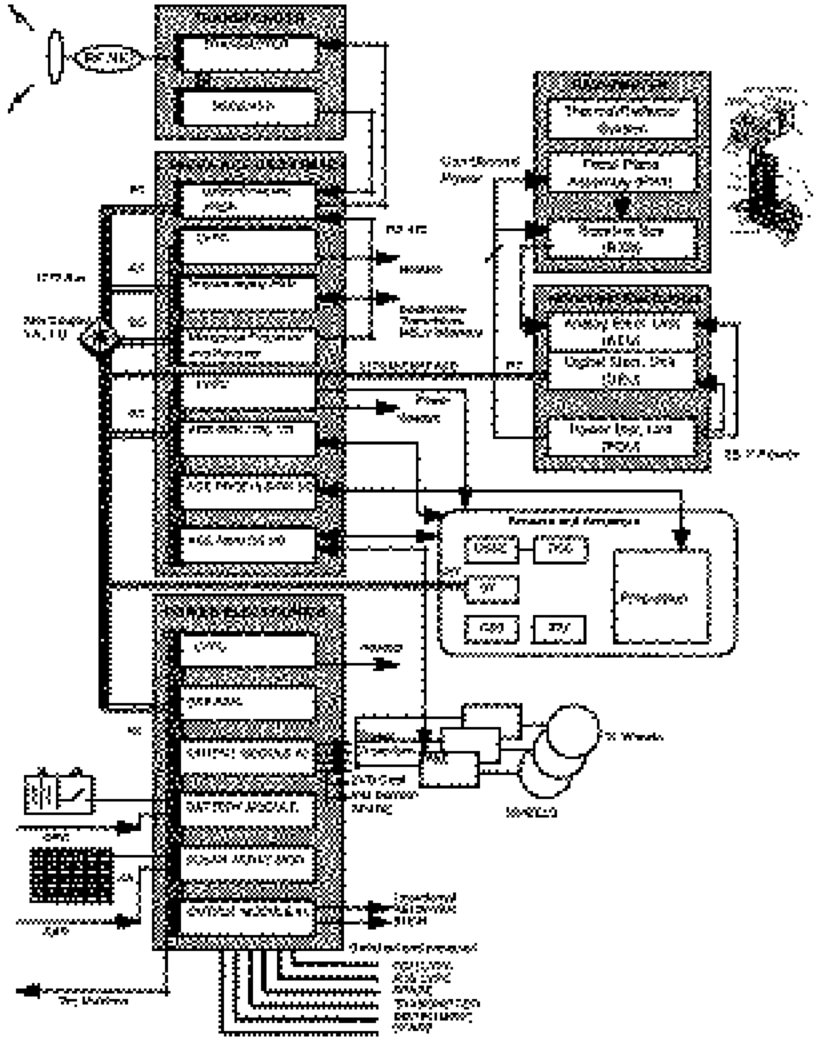
C&DH Top-Level Requirements

- **Uplink/Downlink Reqs:**
  - Support CCSDS Command and Telemetry Protocol
  - Support 2 Kbps command rate
  - Receive/Decode up to eight "Special Commands"
  - Support 37.5 minute dump of full day of H/K & Science data
  - Downlink encoding to maintain Downlink BER
    - RS, CRC, PS, 1/2 & 1/4 CE
- **Processing/Memory Reqs:**
  - Provide capability for C&DH & ACS processing
  - Maintain/distribute S/C time to within 1 msec accuracy
  - Provide 30hr (0.731 Gbit) on-board Memory Storage for H/K & Science data
  - Provide EDAC on memory storage to maintain data storage BER

ACE & RF Top-Level Requirements

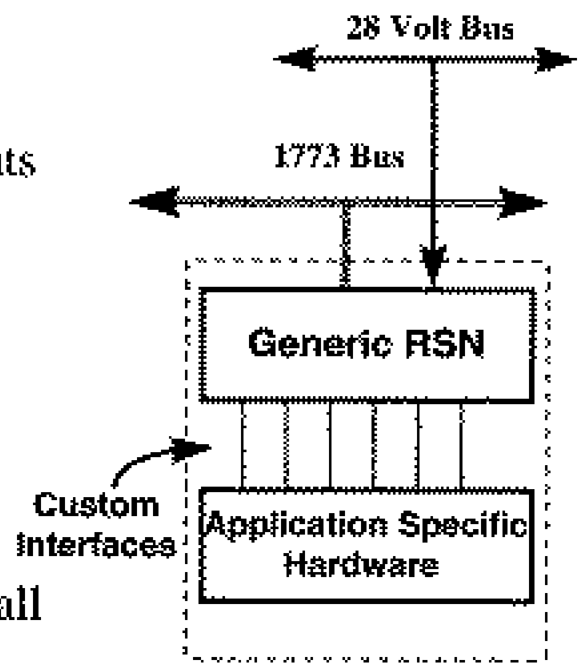
- **ACE Reqs:**
  - Provide Independent Safehold Capability
  - Provide Attitude Control Interfaces from the following sensors/actuators:
    - Coarse Sun Sensors
    - Digital Sun Sensor
    - Inertial Reference Unit
    - Reaction Wheels
    - Propulsion System
- **RF Reqs:**
  - DSN 70-meter antenna required for normal communication
    - Maintain compatibility with 34-meter for backup contingency & phasing loops
  - Full spherical antenna coverage at all times for Uplink commanding
  - Support 37.5 minute dump of full day of H/K & Science data
    - Medium gain antenna necessary to meet data rate required
  - Spacecraft ranging required for orbit/maneuver knowledge

ACE, C&DH & RF in MAP Architecture



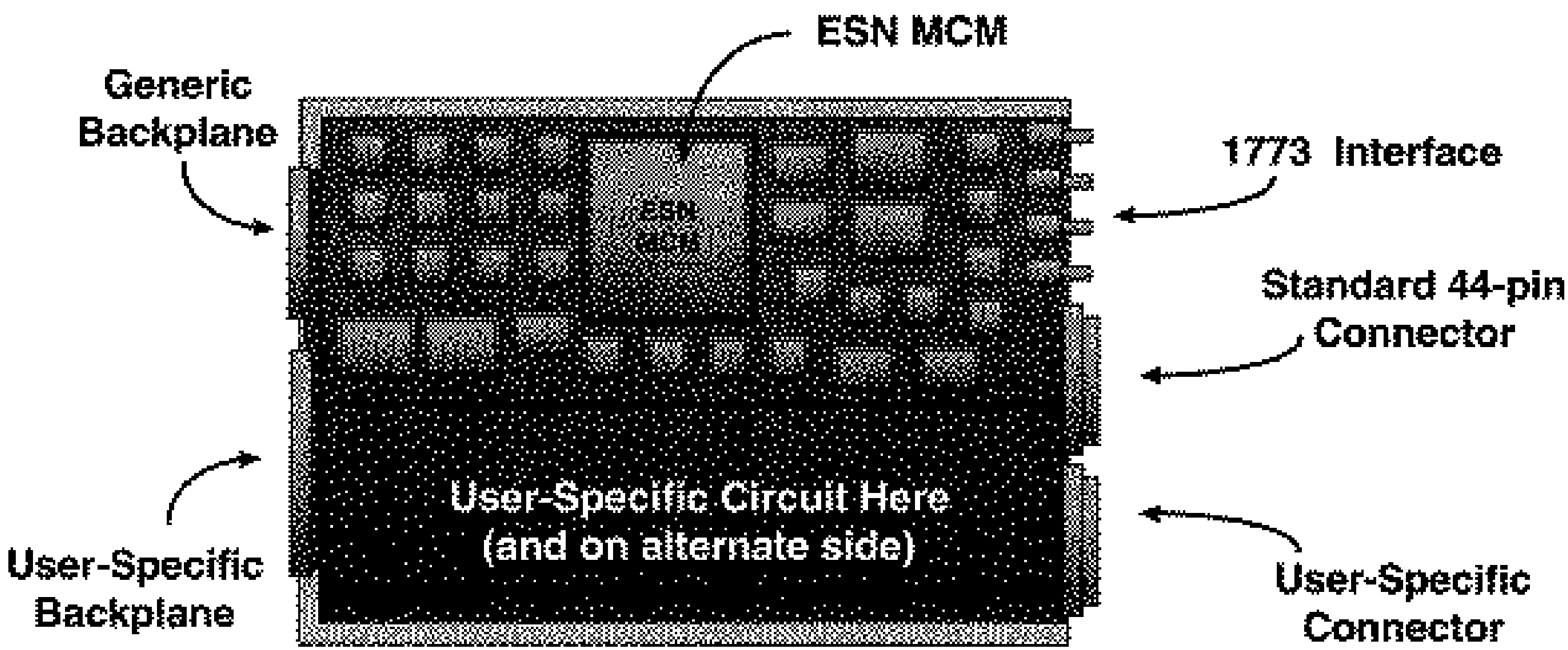
RSN Technology in the MAP Architecture

- Remote Services Node (RSN) implementation allows a modular, distributed architecture
  - Standardized approach for various components to interface with MAP architecture
  - Power and 1773 bus are primary interfaces
  - Standardized, generic H/W and S/W for all subsystems users
- Essential Services Node (ESN) MCM is the core of the RSN approach
  - Analog/digital H/W module implemented in all RSNs as standard I/F component
  - Developed as flexible, cost effective H/W & S/W interface tool to allow advanced distributed architecture implementation

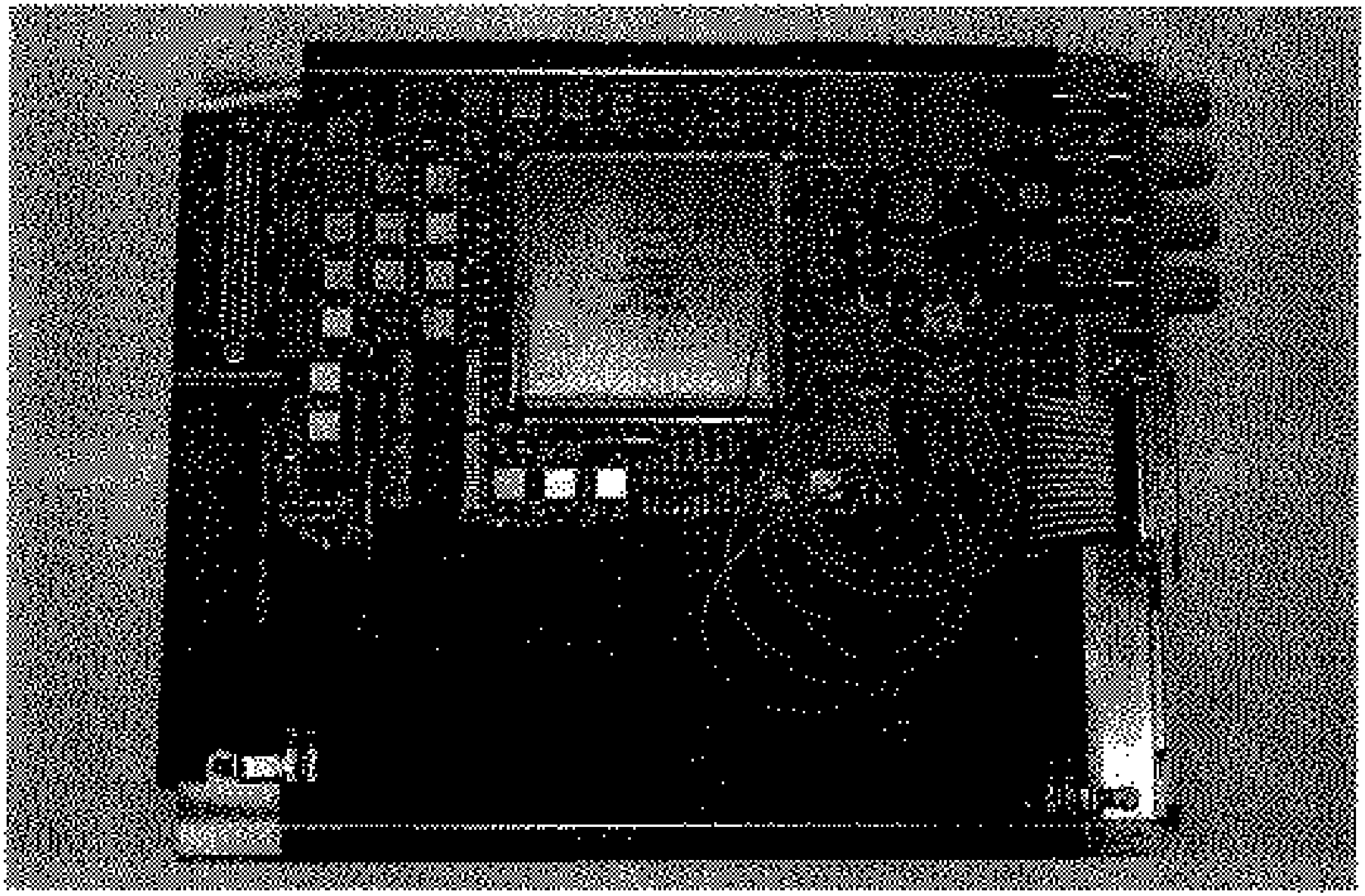


Generic RSN Core Implementation Approach

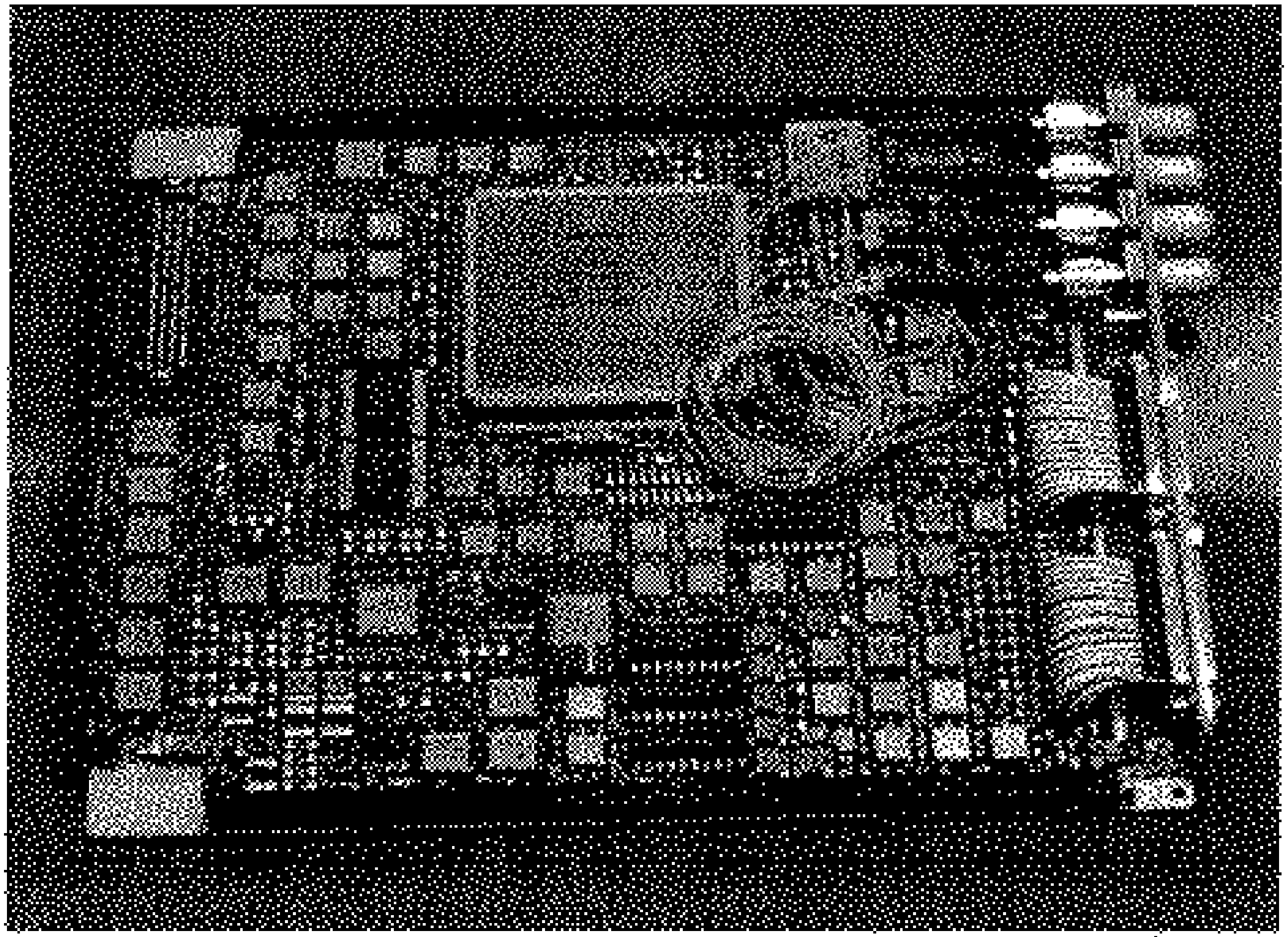
- Generic RSN Core Design on 1/2 of one side of card
- Remaining 1/2 side and alternate card side used for User-specific circuit
- Allows standardized H/W and S/W spacecraft interface



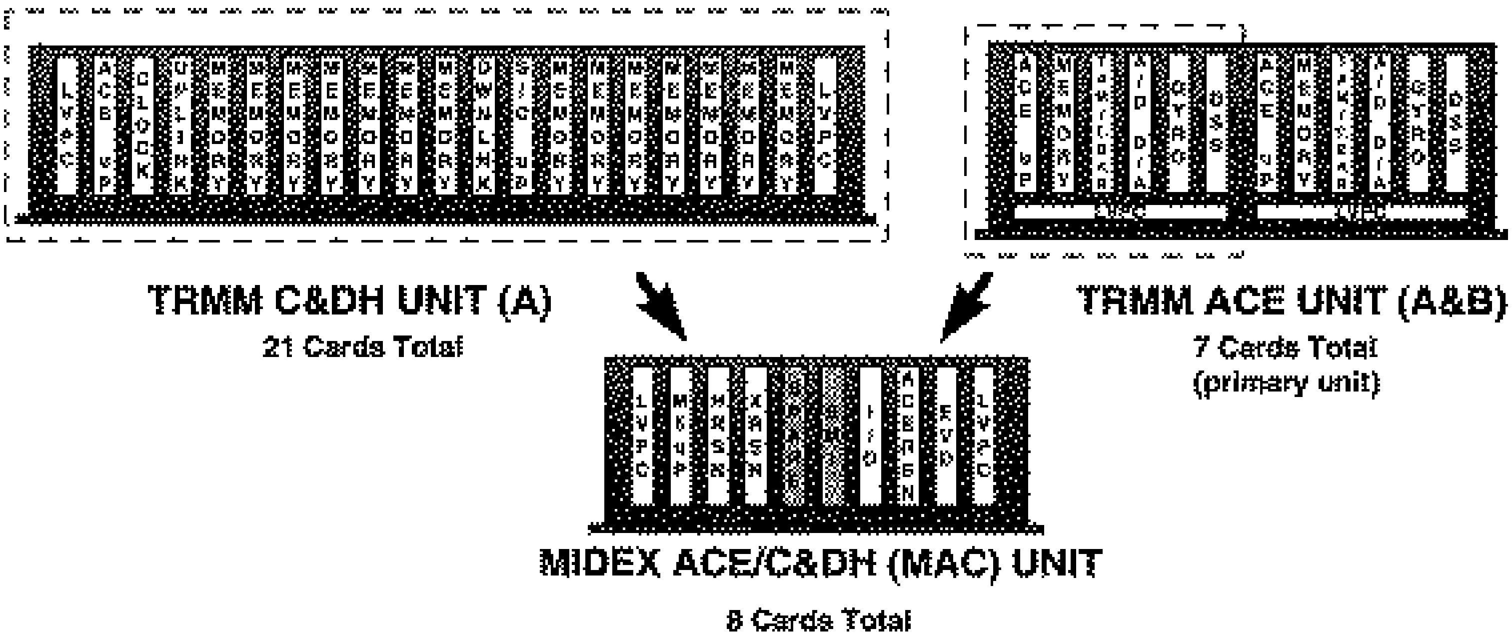
Actual Generic RSN Core Design Implementation



Actual PSE RSN ETU Implementation

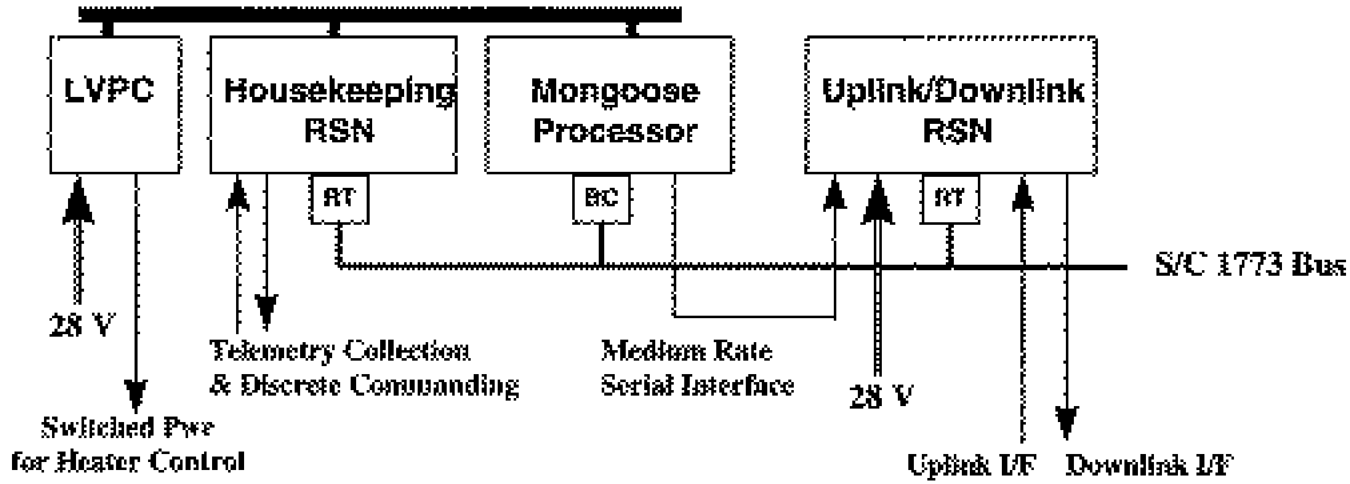


MIDEX ACE/C&DH (MAC)
Unit Concept



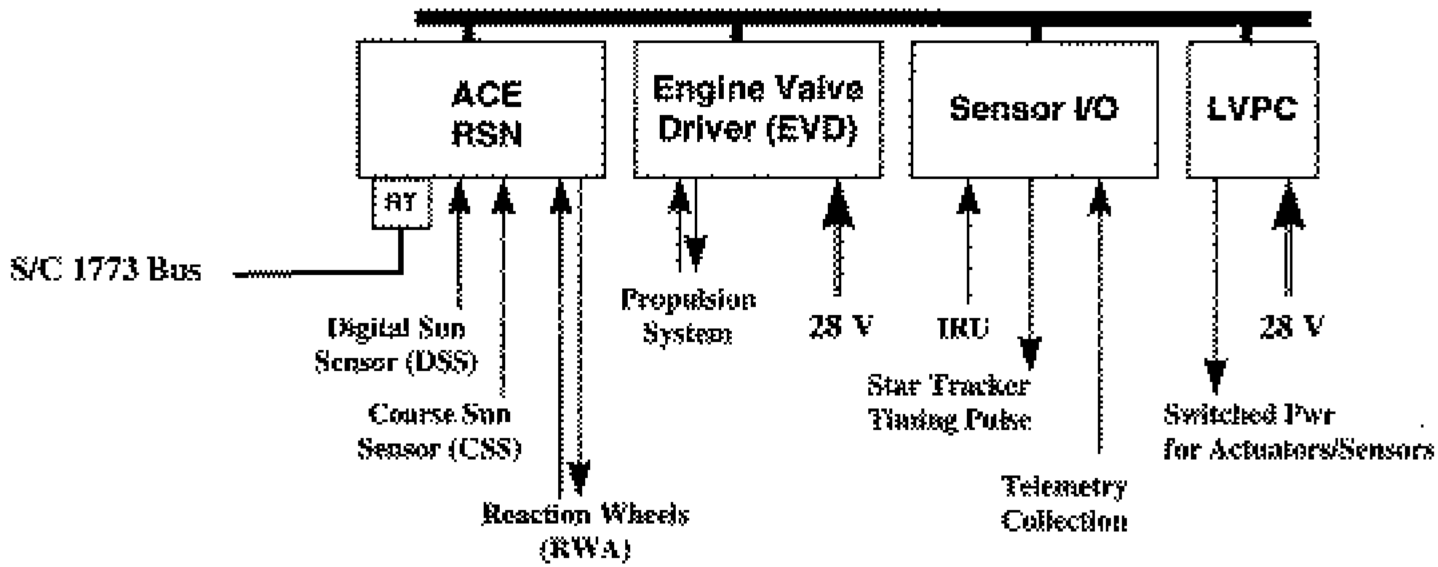
- Decreased Weight, Size, Power; Increased Performance
- Flexible, Modular Design Can Be Configured to Specific S/C Application
- Includes Additional Functions Previously Residing in PSDU (eliminates additional box types from S/C)
- Standard Interfaces & Modular Architecture Simplifies Box I&T

C&DH Architecture Diagram



- Power and 1773 are Primary S/C interfaces
- Mongoose Processor card performs as S/C & ACS Processor
- Housekeeping RSN
  - Performs S/C Telemetry Collection & Discrete Commanding
  - Separation signal, Deployables control, etc..
- Transponder RSN provides Uplink Downlink I/F to Transponder
  - Hardware-decoded "Special commands" to S/C subsystems
- Medium Rate Serial I/F transmits stored data directly from M-V to XRSN
  - Incorporated into downlink telemetry stream along with real-time H/K telemetry

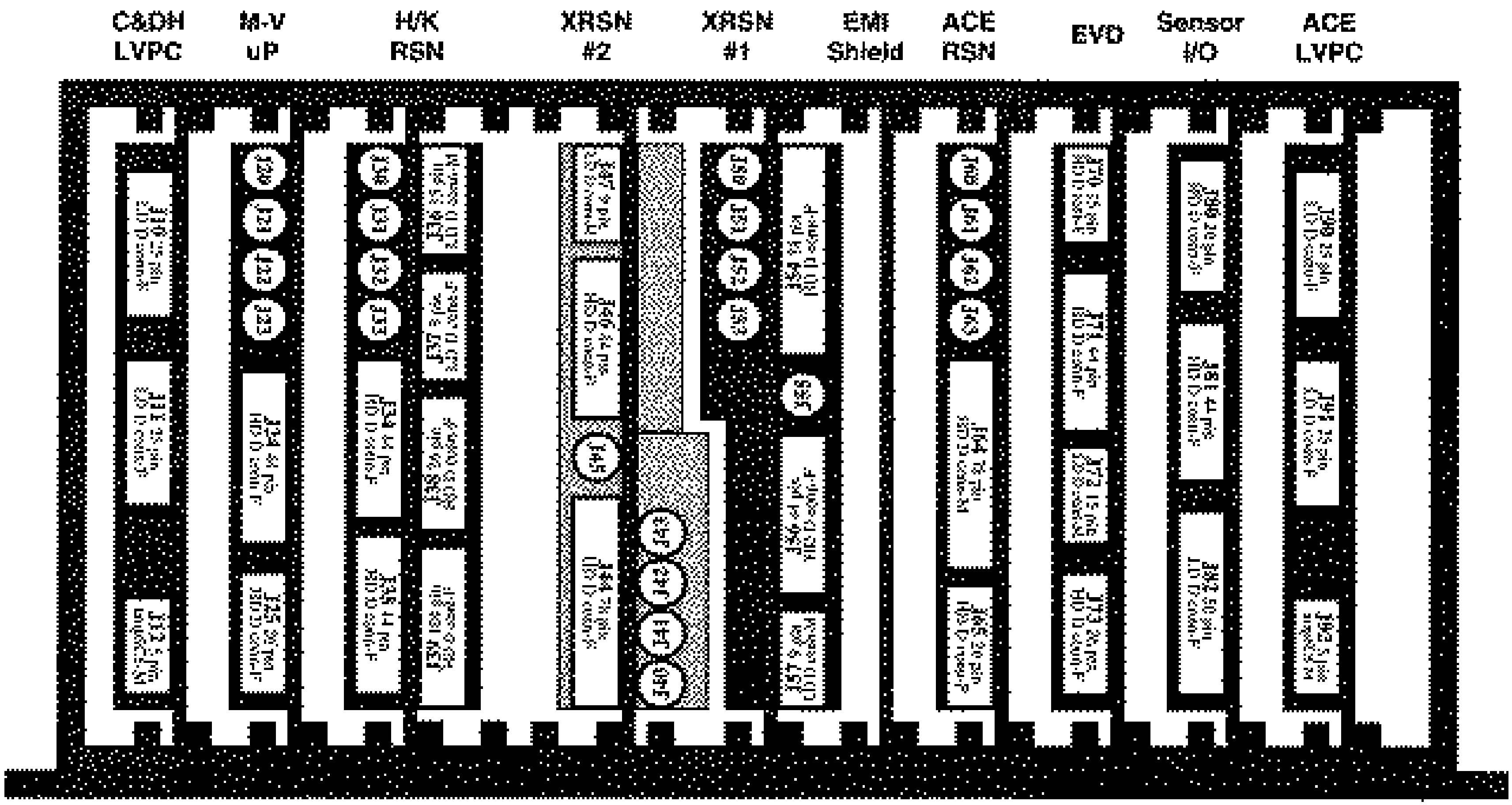
ACE Architecture Diagram



- ACE RSN acts as Independent Safehold processor
- Sensor I/O data collected and distributed over backplane to ACE RSN
  - Separation signal, solar array deployment information, etc..
- EVD provides thruster control for ACS commanding
- LVPC switched outputs under ACE RSN control
  - Provides switched power outputs to ACS components

MAC Unit Configuration Diagram

C&DH, ACE & RF

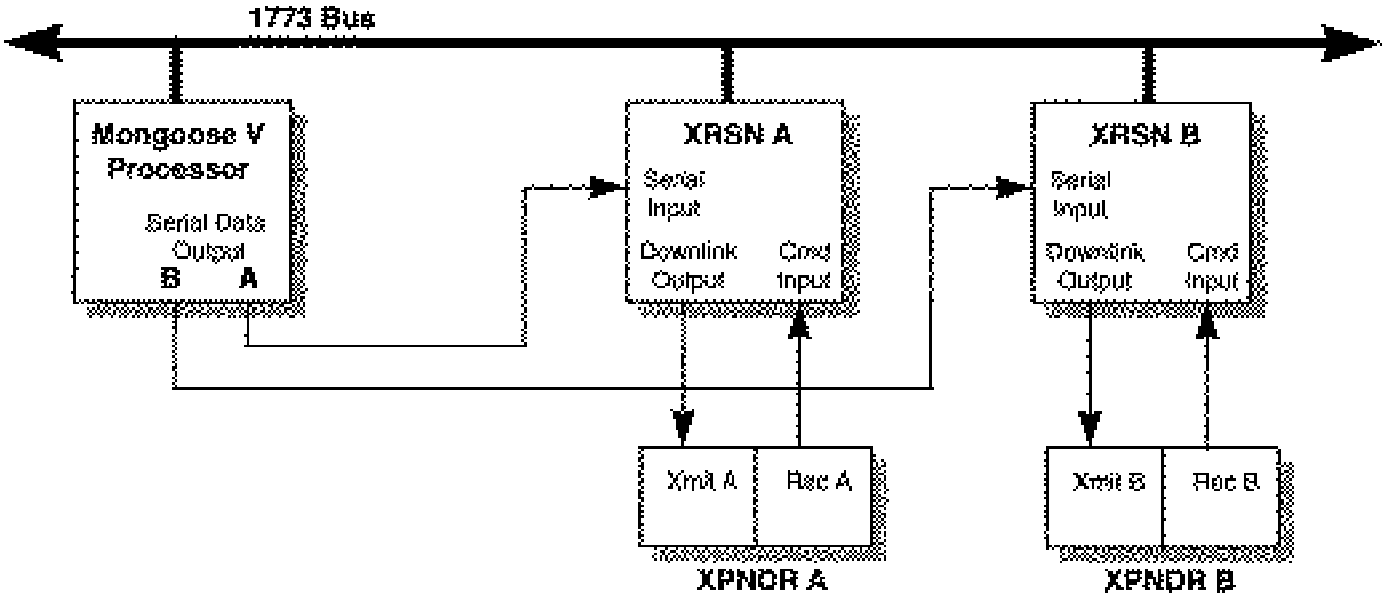


Baseline Configuration

Optional Redundant XPNDR

Note: Connector sizes are representations only

MAP Redundant XPNDR Implementation Option



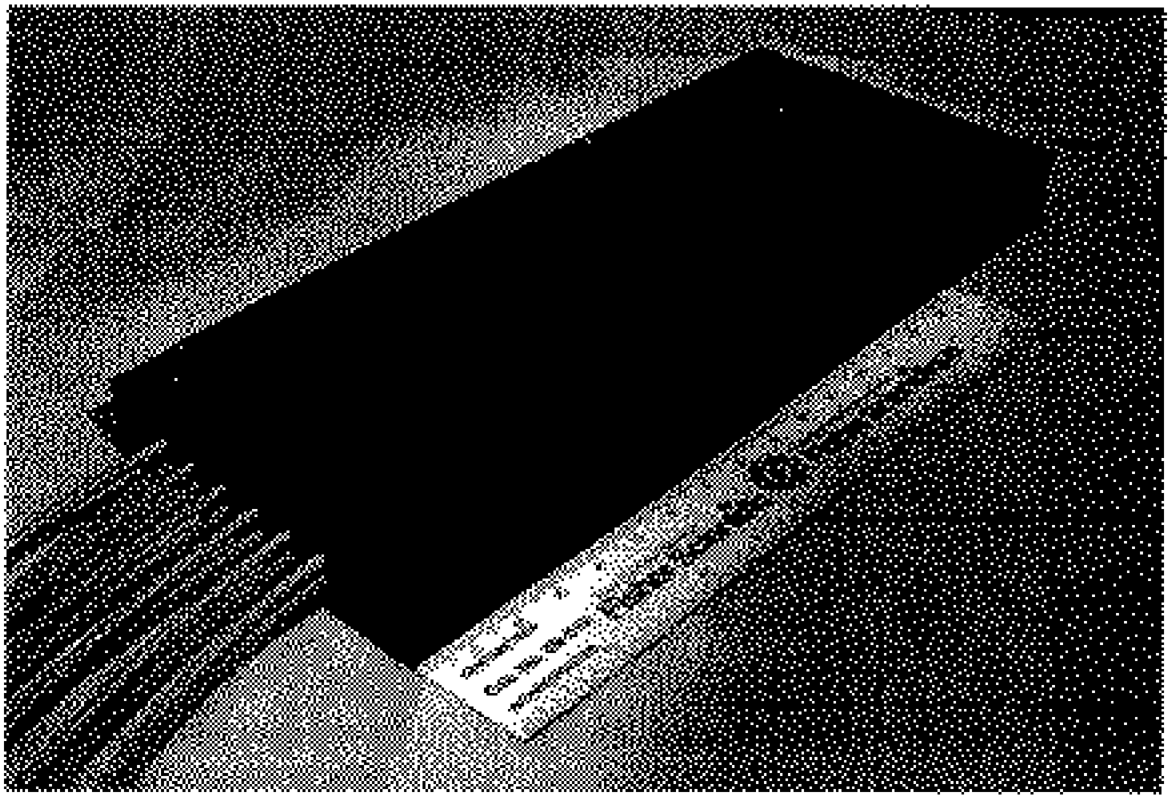
- Command Interface:
  - Command input cross-strapping between M-V and XRSNs via 1773 bus
  - Single XRSN Uplink selected by ground as "active"; can only be changed by ground command to "inactive" XRSN Uplink
- Downlink Interface:
  - Downlink cross-strapping between M-V and XRSNs via multiple serial outputs
  - Redundant XPNDR transmitter is off (only one transmitter powered at a time)

1773 Star Coupler Description

- Pigtailed Coupler consists of a 12x12 configuration installed in a light weight aluminum housing.
  - Spectran 171.2um Polyimide fiber to be used
  - Fused Biconic Taper (FBT) Coupler
  - 1300nm multimode system
- 2 Couplers to be used on MAP (primary & redundant 1773 bus)
  - Coupler designed by Code 733
  - Coupler fused together and built by Canstar (Toronto, Canada)
  - Staggered fiber lengths inside housing to permit OTDR mate verification
  - 1773 bus margin verification to be performed as part of MAP S/C I&T
- FC connectors used, manufactured by Johanson Mfg. Co.
- Cable jacketing is same as that flown on SAMPEX and RXTE

1773 Star Coupler Prototype

- Significantly lighter and smaller than XTE/TRMM couplers
  - Dimensions: 3.5" w x 8" l x 3/4" h
  - Total weight of coupler and cable: 1.6 kg

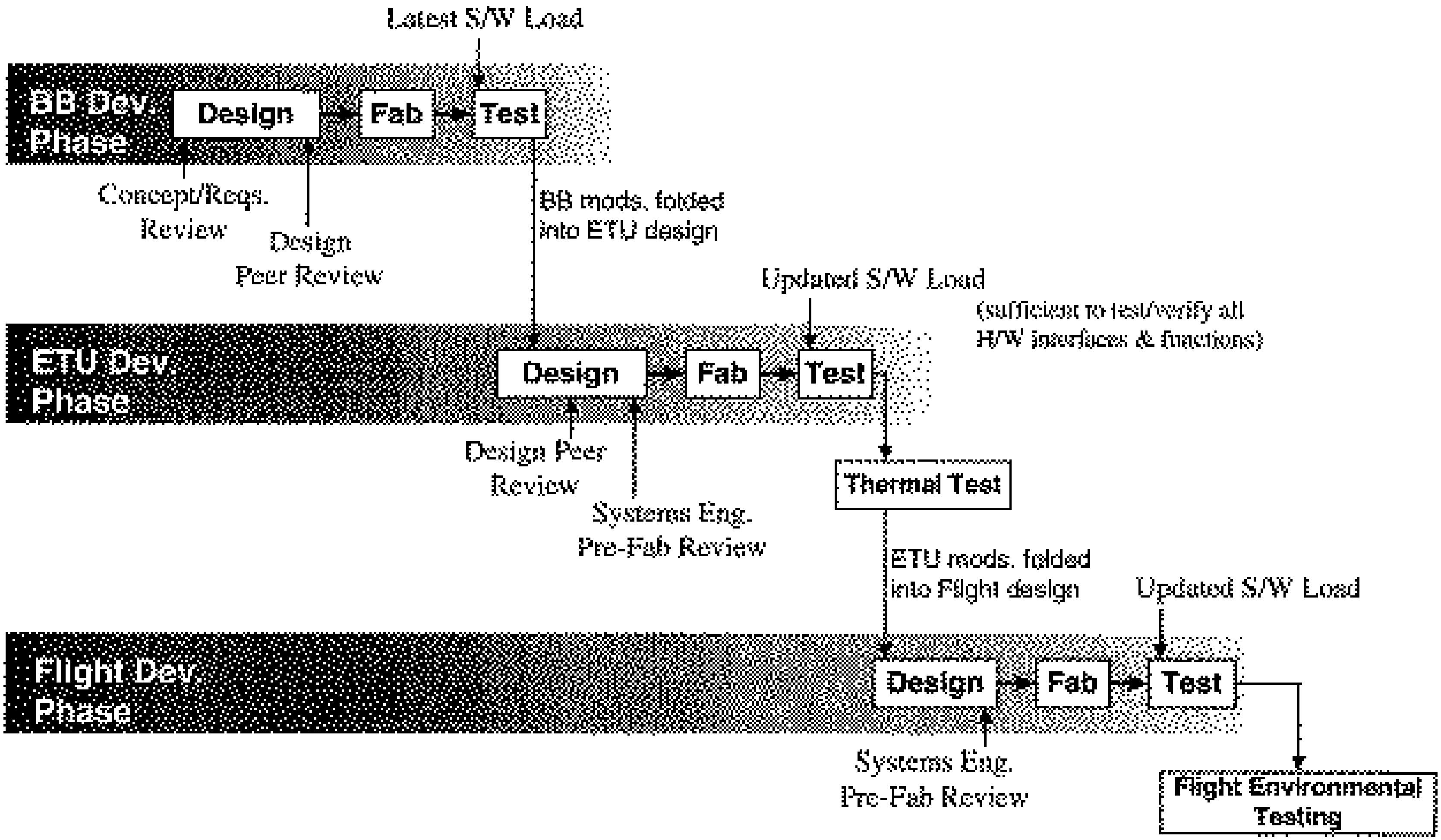


MAC Development/Verification Process & Status

- MAC Development Status
  - All MAC Breadboards completed and tested
  - All ETU boards either in layout or fabrication
- MAC Development and Verification
  - All cards designs had separate Requirements/Concept review and Design Peer review before card layout
  - All ETU designs required to undergo final detailed schematic and design implementation review by MAP System Engineering Team before ETU layout
  - MAC ETU hardware to undergo full functional test during thermal cycling to validate design before Flight build approval
    - Utilizing S/C GSE for ETU testing in flight operational mode
    - Same testing and procedures to be used in flight unit testing
- MAC Hardware Design and Test Methodology
    - See MAC Design and Test flowchart

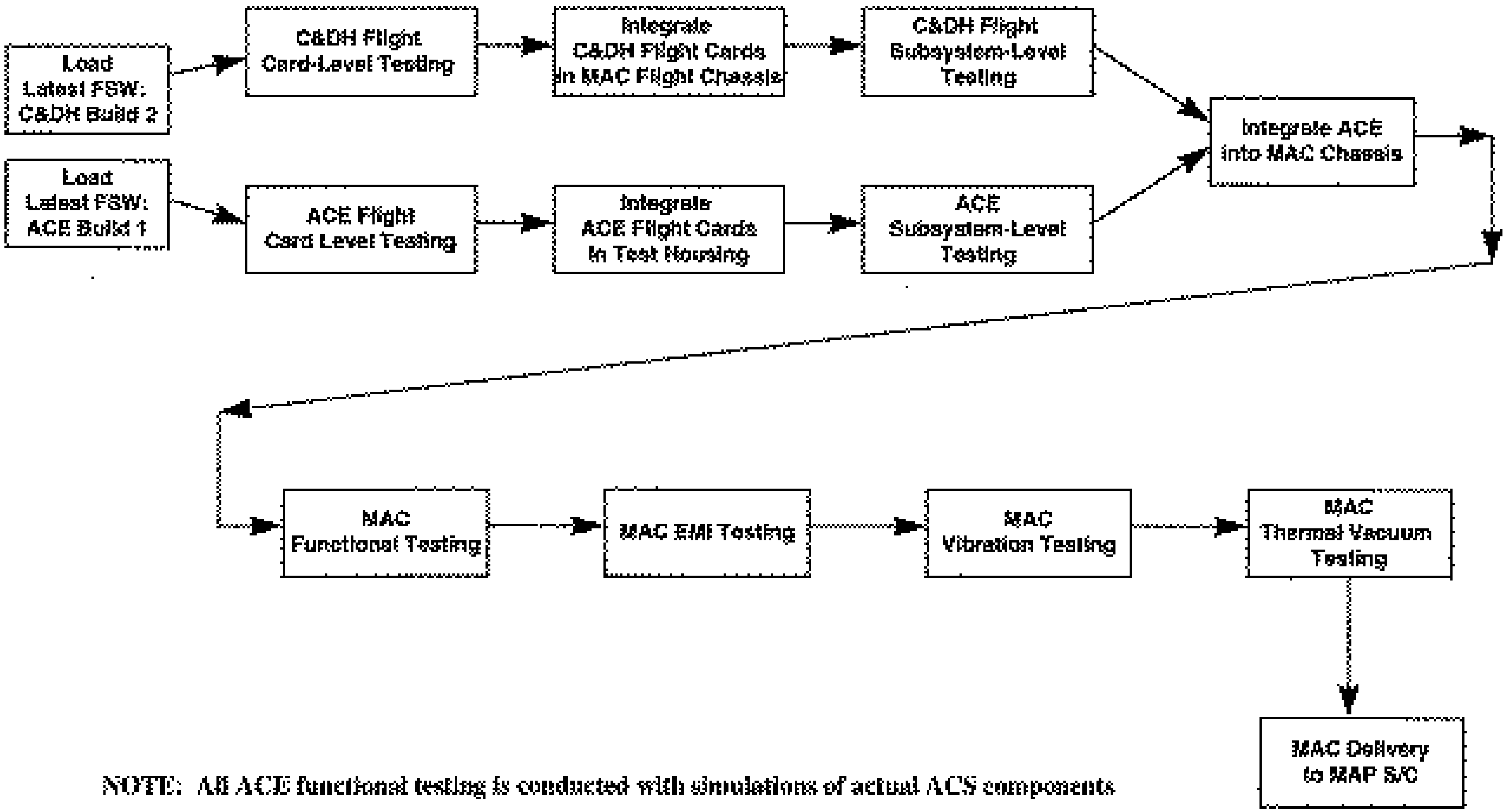
MAC Design & Test Flowchart

C&DH, ACE & RF



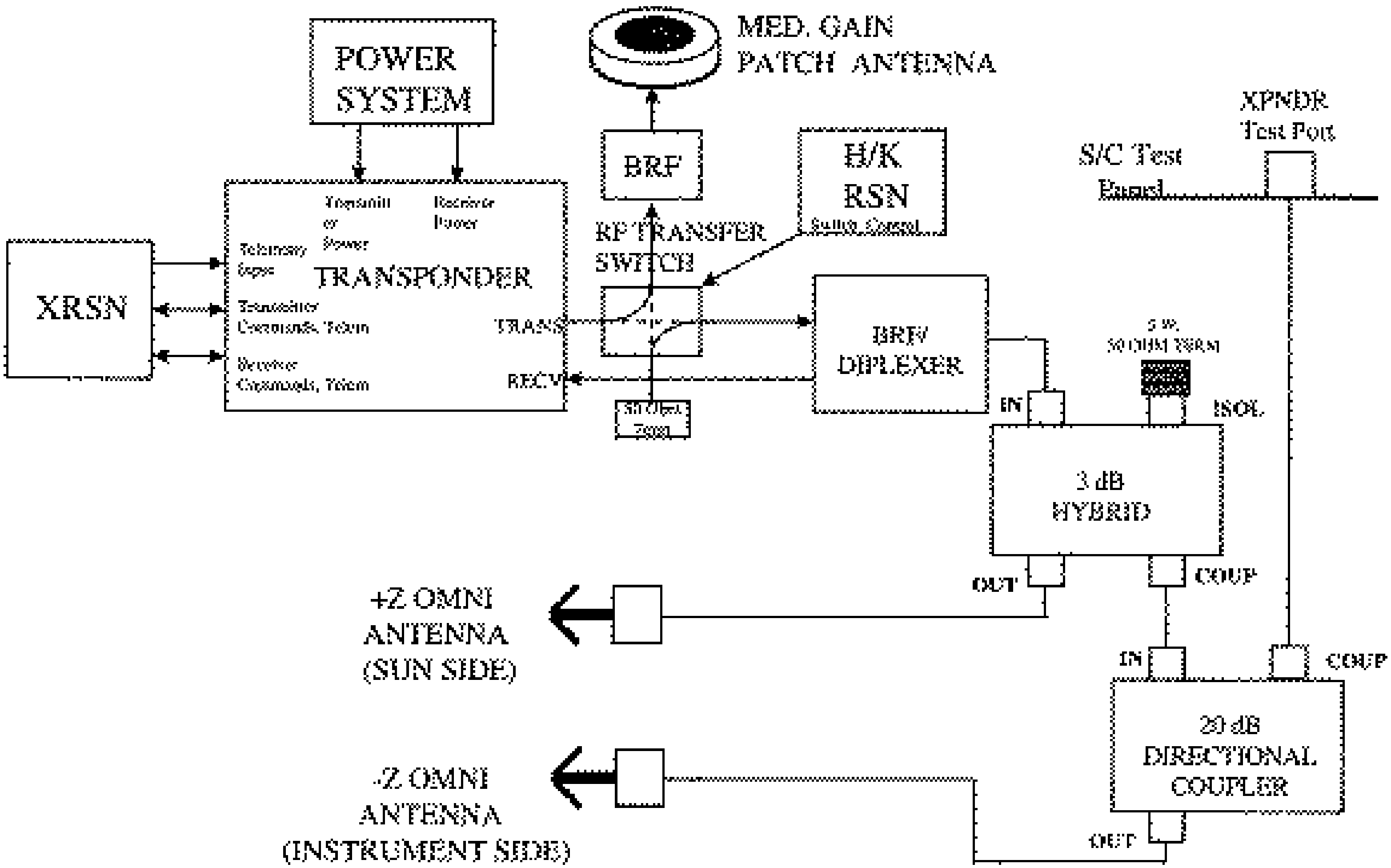
MAC I&T Flow

C&DH, ACE & RF



NOTE: All ACE functional testing is conducted with simulations of actual ACS components

MAP RF Communications Configuration Diagram



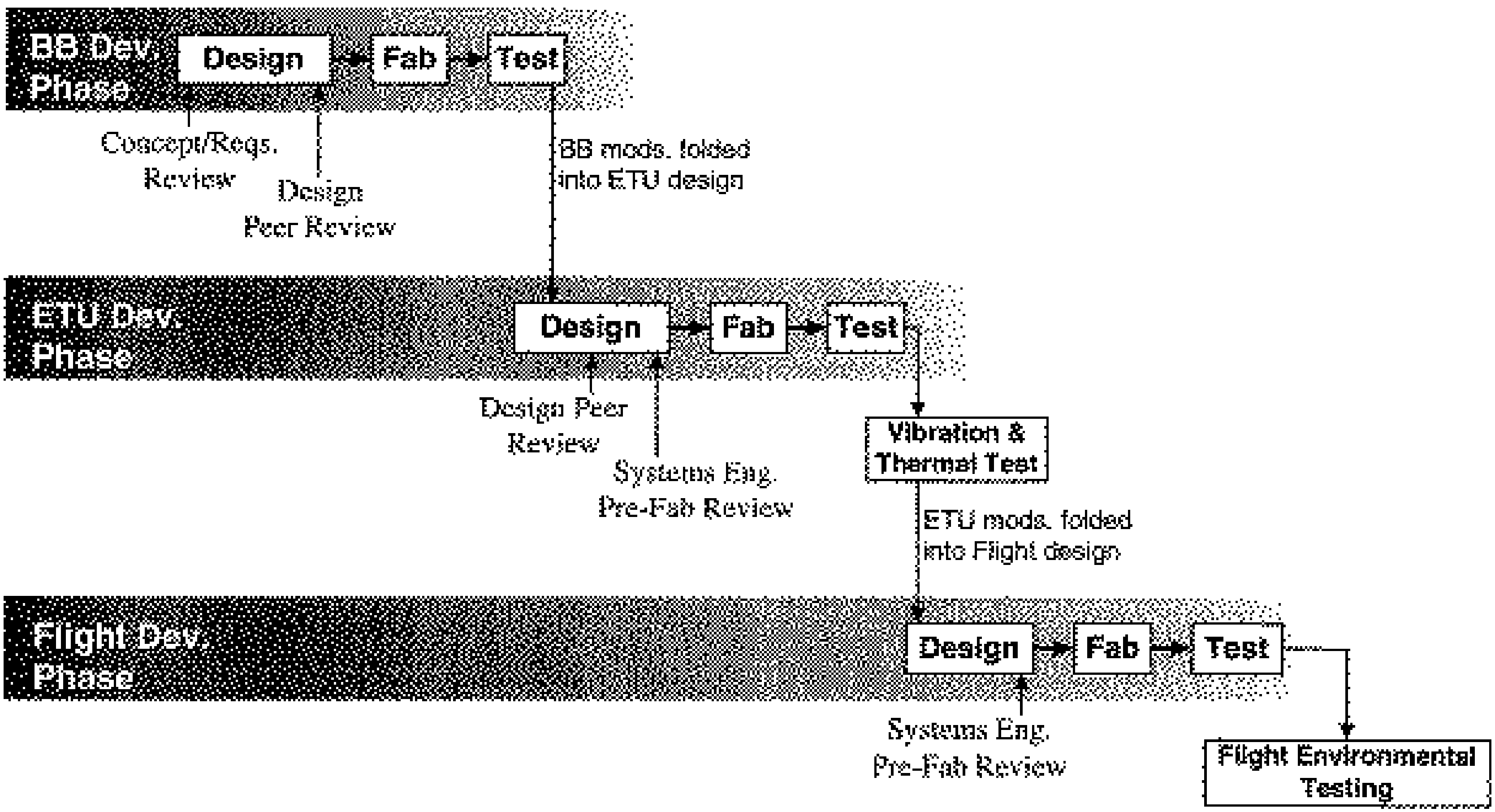
MAP GN Transponder

- Currently procuring GN transponder
  - In process of evaluating proposals
  - Anticipating transponder award approximately August 19, 1997
- GN Transponder specified characteristics:
  - $\geq$ 5 Watt RF output power
  - $\leq$ 37.8 W DC power (< 3.8 W receiver, < 34 W transmitter)
  - Uplink modulation: 2 Kbps Command data on 16 KHz subcarrier, PM onto S-band carrier
  - Downlink modulation: Telemetry data PM directly onto S-band carrier
  - 5.5 MHz max. downlink bandwidth
  - < 8.9 lbs. (transponder + diplexer)
  - Uplink Freq. = 2090.66 MHz, Downlink Freq. = 2270.4 MHz
  - Transponder Spec. reviewed by DSN

MAP Antennas

- Omni Antenna
  - Cupped Dipole design
  - Significant heritage on other flight programs (XTE, TRMM, TRACE)
  - 0 dBi gain over $\pm$ 80° from boresight
  - Build-to-print design, in-house testing and verification
  - Thermal issues addressed
    - Omni & RF cable qualification test to - 200°C for cold thermal extreme
- Medium Gain Antenna
  - Circular patch design
  - In-house design, build, and testing
  - > 5.5 dBi gain over $\pm$ 35° from boresight
  - Designed for $\pm$ 100°C (direct sun)
  - ETU designed, built, and verified identical to flight to validate design
    - See Design & Test flowchart

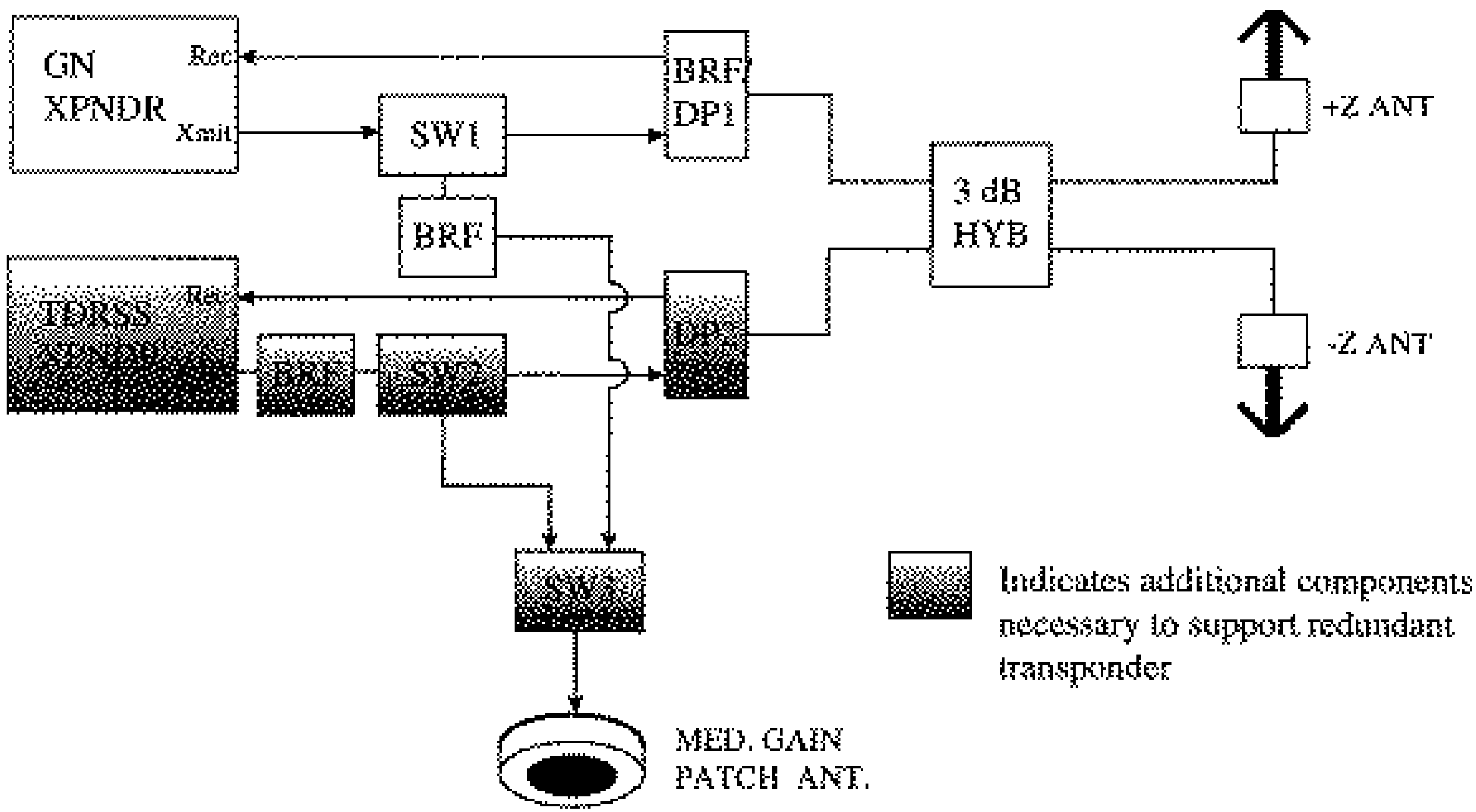
MAP Medium Gain Antenna Development Flowchart



Verification of Procured Components

- Transponder(s) :
  - Vibration, Thermal Vac./Cycling, and EMI/EMC testing to MAP component qualification levels.
- RF Switch(es):
  - Operational Run-In of 1000 cycles each at -20, +25, and +60°C
  - Random Vibration to MAP component qualification levels
  - Two thermal cycles
- Hybrid, Coupler:
  - 5 cycles of Thermal Shock testing performed per MIL-202, Method 107
  - Vibration testing at observatory level.
- RF Cables:
  - Gore coax will be tested to -200°C with -z omni at GSFC
  - Manufacturer will test flight cable assembly to -180°C
  - All other flight cables will be verified at observatory level.

MAP RF Redundant Transponder Configuration

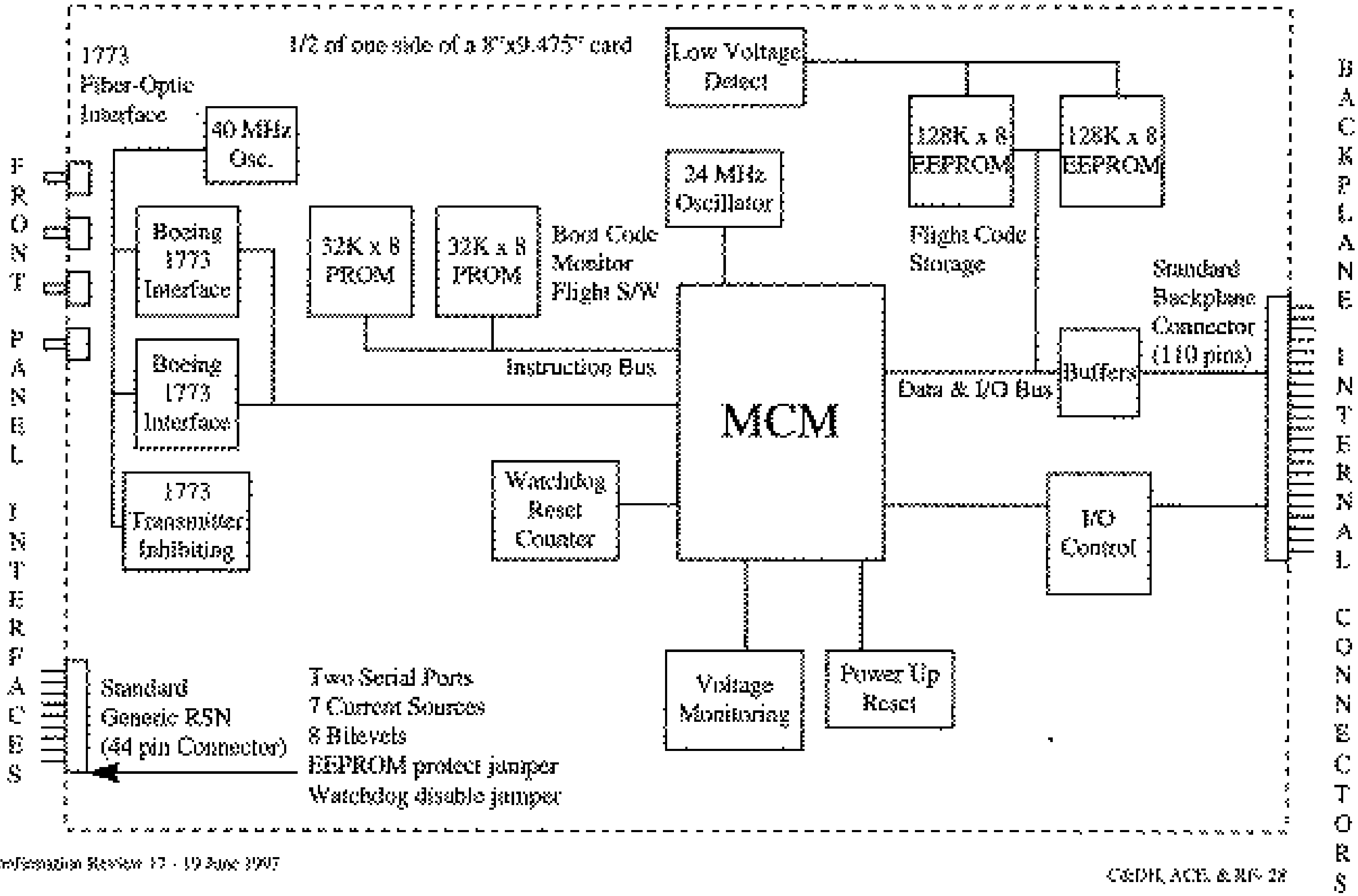


Conclusions

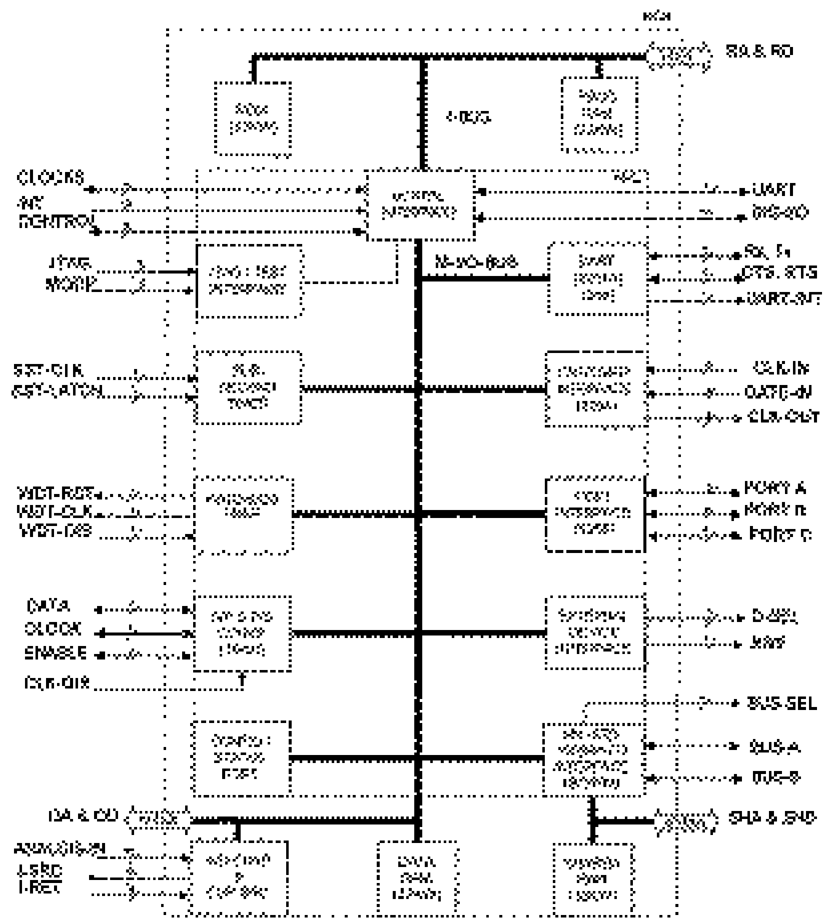
- Requirements, approach & designs complete and stable
- Hardware development progressing
  - Breadboards completed and currently being used for S/W development
  - ETU cards either in fabrication or layout
- Development and implementation plan well-defined and meets MAP technical and resource requirements

Backup Viewgraphs

Generic RSN Core Block Diagram



Generic RSN Core Capabilities

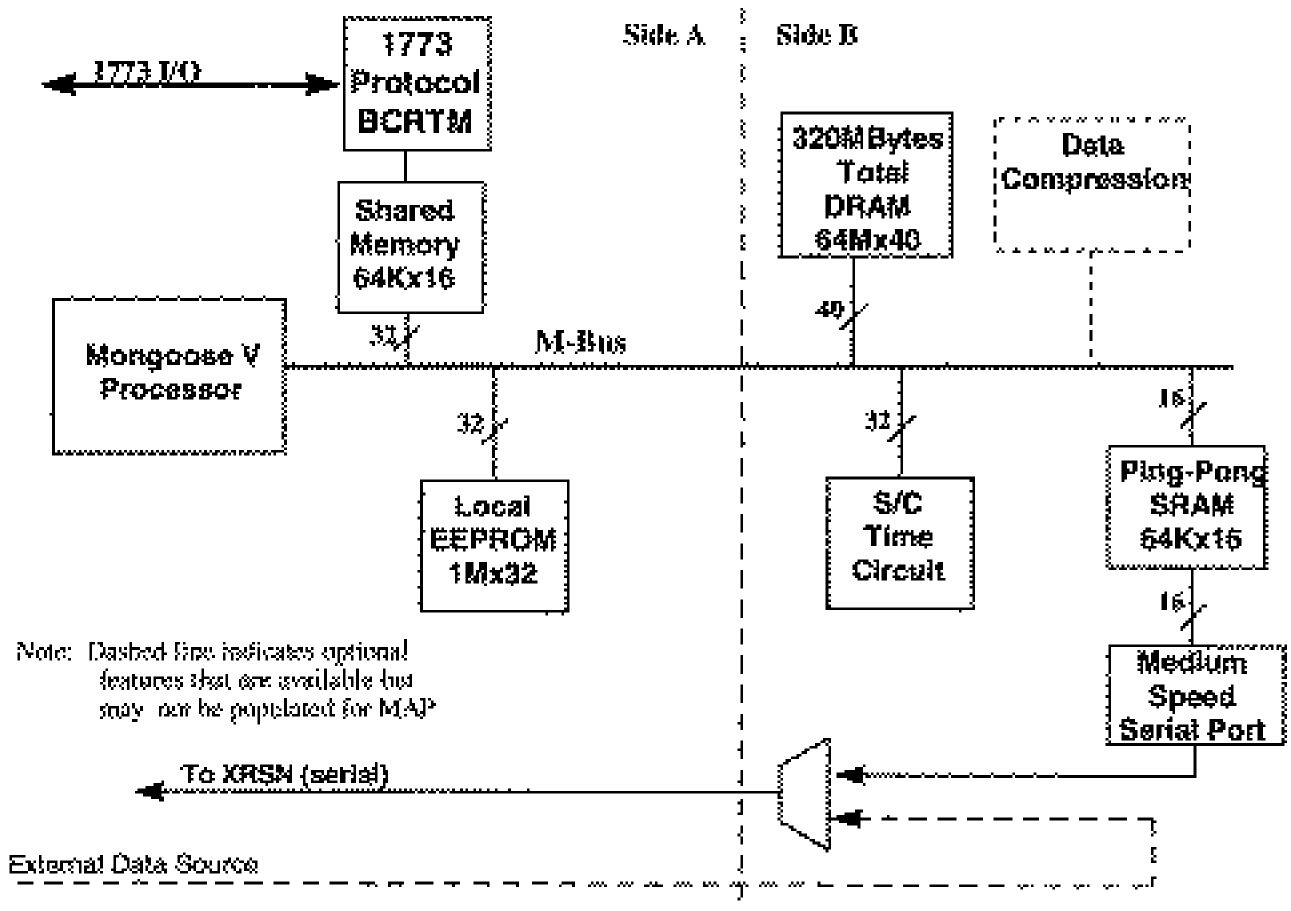


THE ESSENTIAL SERVICES NODE (ESN)

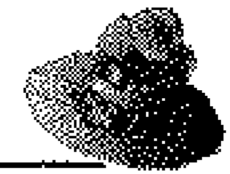
ARCHITECTURAL BLOCK DIAGRAM

Mongoose V Processor Block Diagram

C&DH, ACE & RF

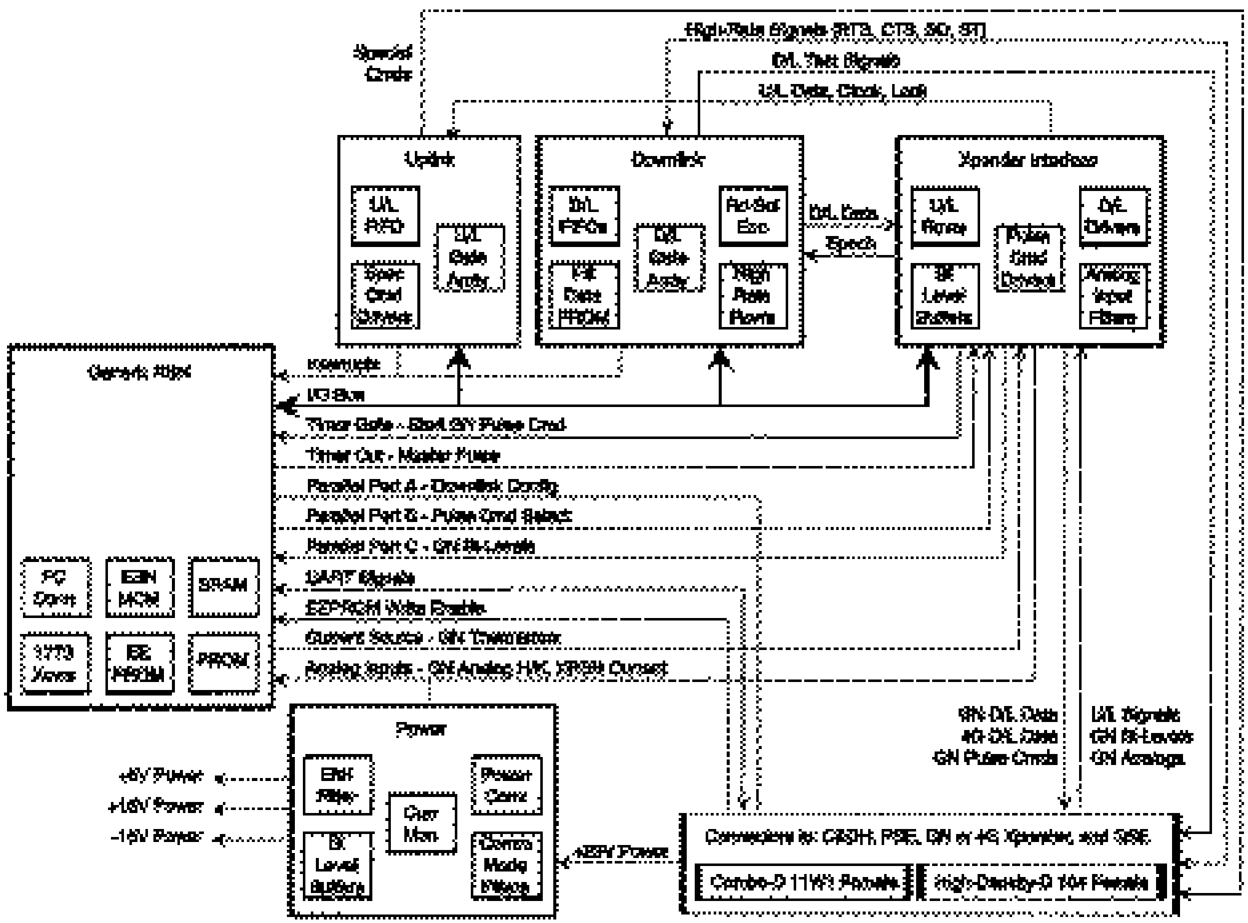


Mongoose V Processor Functions

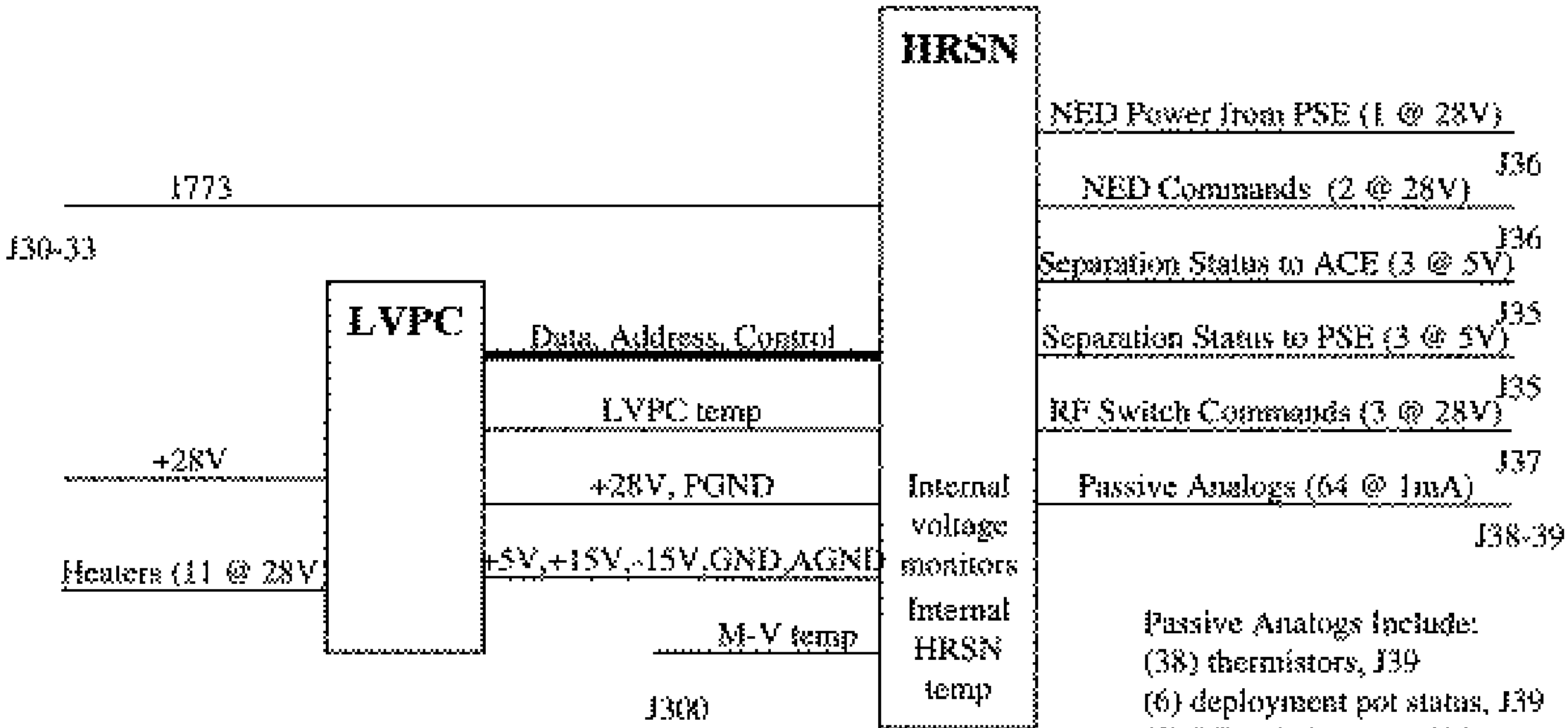


- Single Mongoose V 32-bit Rad-Hard RISC Processor
  - R2000/R3000 Instruction Set Compatible CPU(LSI Logic LR33000 Core)
- 4MBytes of Jumper Configurable (64KByte steps) EEPROM (1Mx32)
  - Write-Protected Bootstrap Region, Boot Region, Flight-Writeable Region
- 1773 Bus Controller Shared Memory Interface
  - Based on HST & Landsat 7 ASSR Processor Implementation
- 256MBytes ofDRAM
  - 256 Mbytes (4Mx32) of Data Storage, 64 Mbytes (64Mx8) of EDAC
- Spacecraft Time Keeper
  - 32-bit Seconds Counter,22-bit Microseconds Counter,Reset on power cycling only
- Watchdog Timer
  - 16-bit interval timer clocked at 16Hz (62.5ms resolution)
  - Generates software reset upon timeout unless WD timer is re-loaded
- External Timer
  - 16-bit interval timer clocked at 60KHz (16.6us resolution)
- Serial Output port to XRSN
  - Selectable from 1, 2, 4, & 8 Mhz data rates
- Data Compression Option
  - Utilizes FIFO-buffered USES Compression Chip
- External Waitstate Generators

XRSN Block Diagram

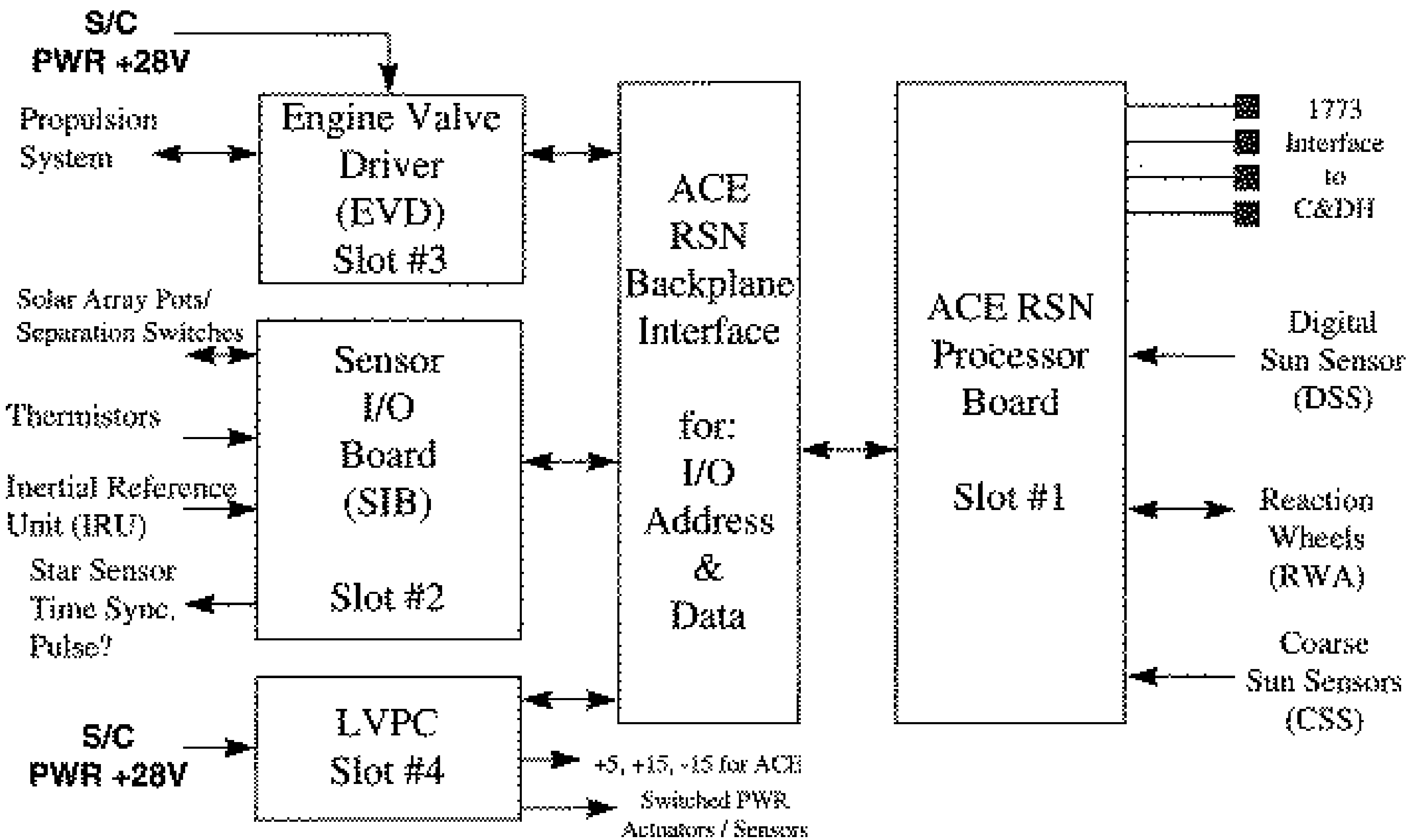


Housekeeping RSN Interfaces

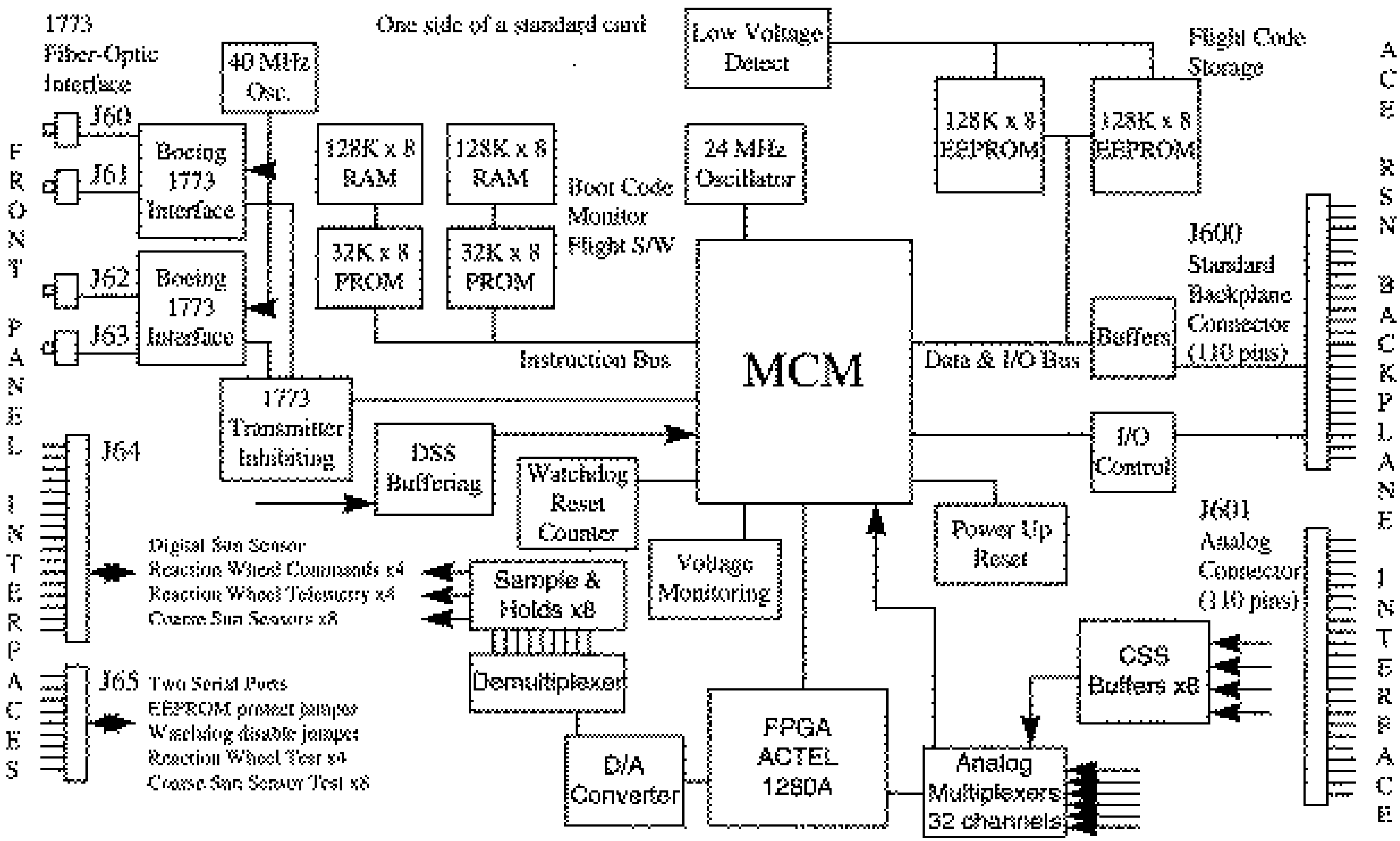


Passive Analogs include:
(38) thermistors, J39
(6) deployment pot status, J39
(3) RF switch status, J38
(3) separation status, J38
(2) NED arm plug status, J38
(2) EVD arm plug status, J38
(2) NED pin status, J38

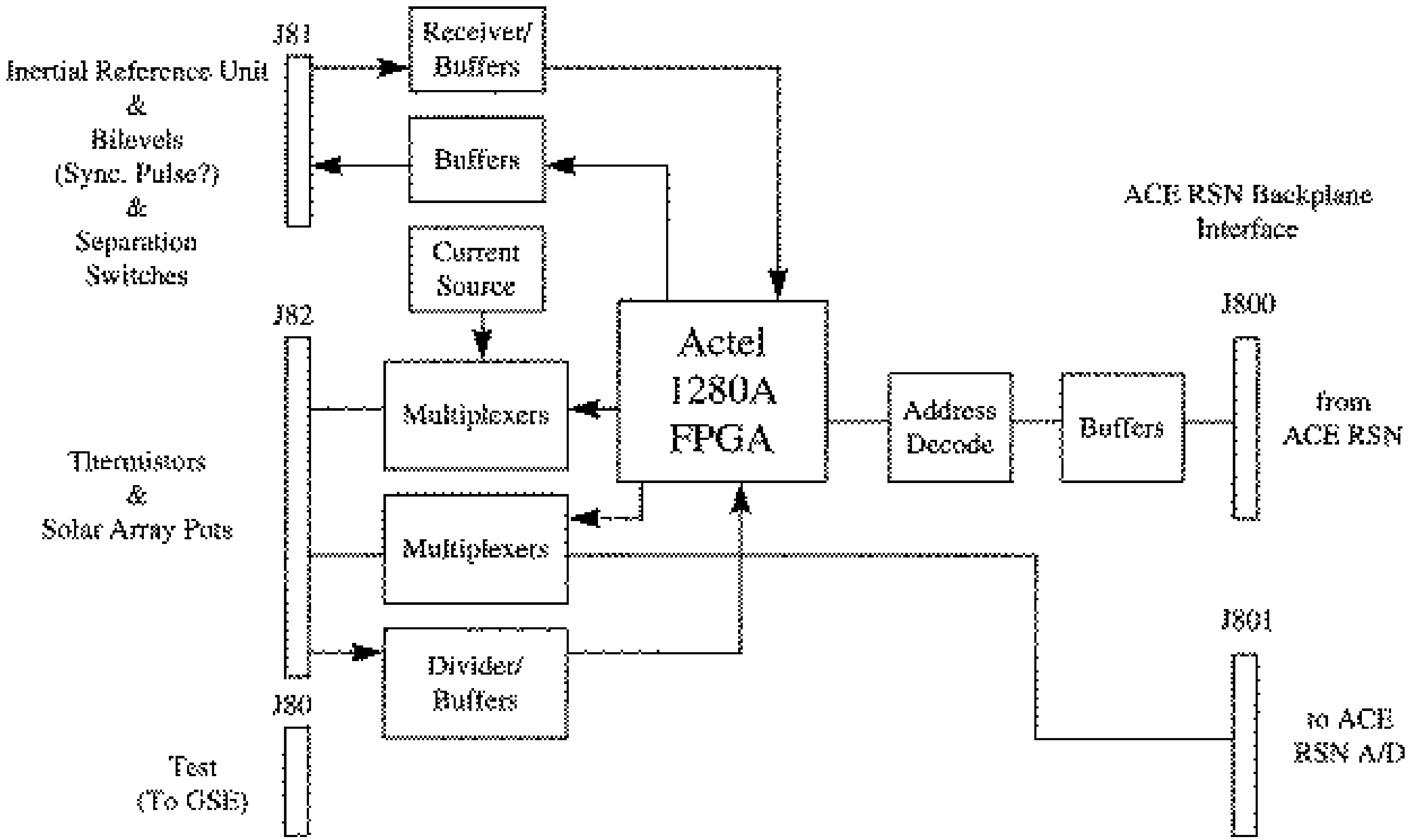
ACE Block Diagram



ACE RSN Card Block Diagram

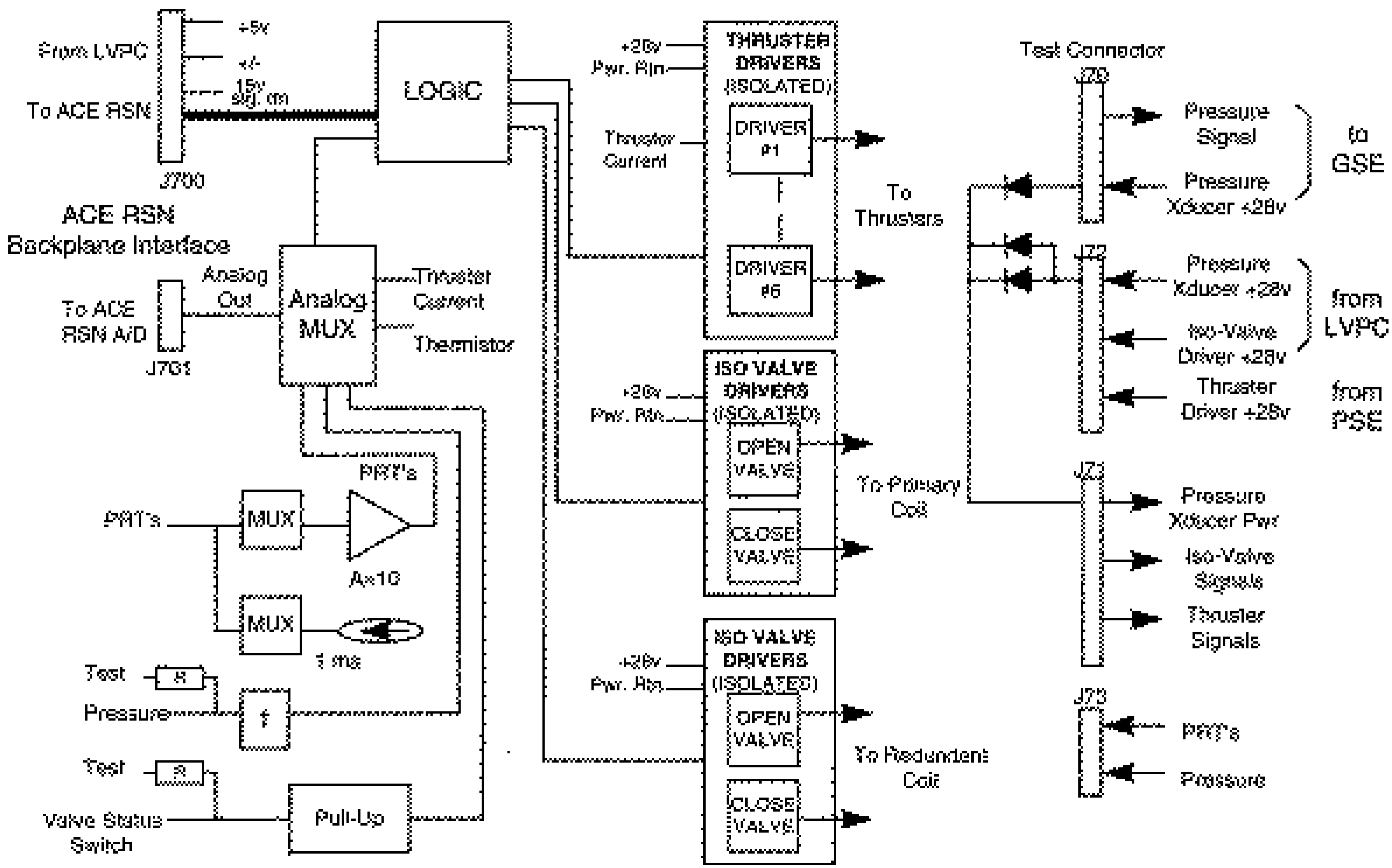


Sensor I/O Card Block Diagram



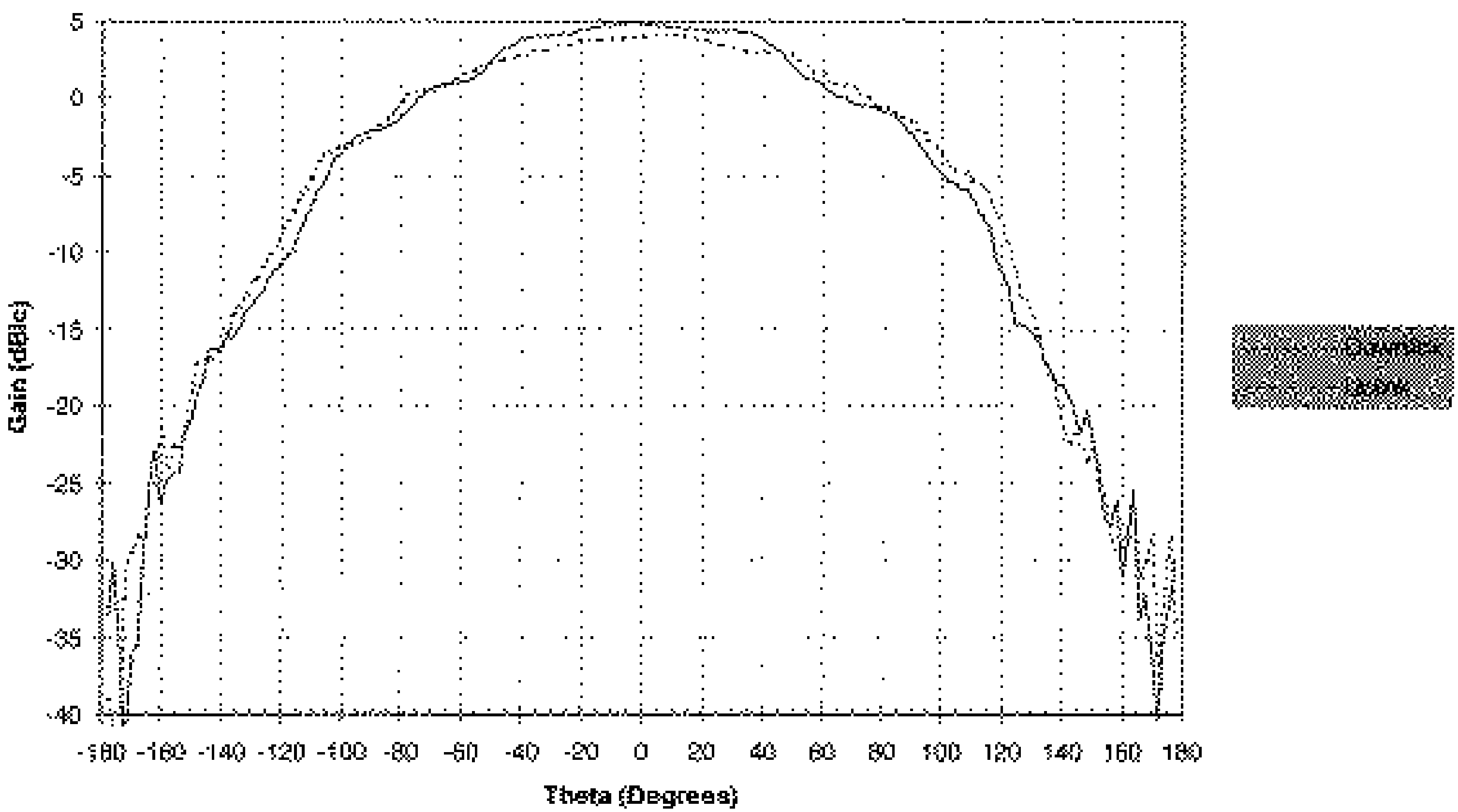
C&DH, ACE & RF

Engine Valve Driver Card Block Diagram

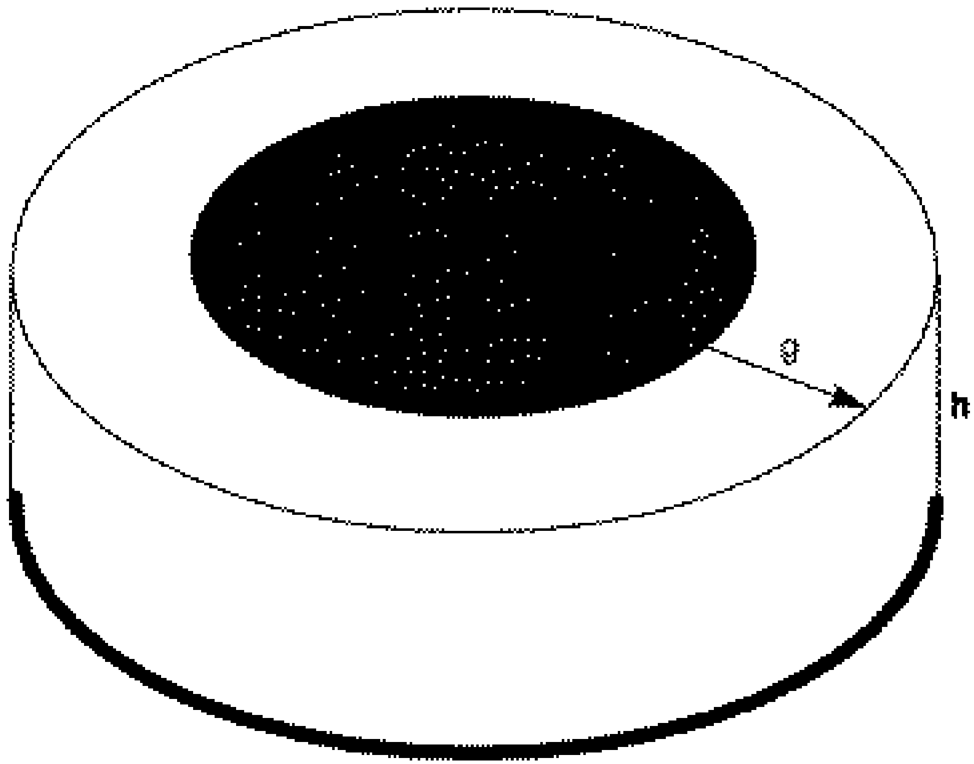


Omni Antenna Patterns

C&DH, ACE & RF



Baseline Medium Gain Antenna



h = 125 mils, or 60 mils

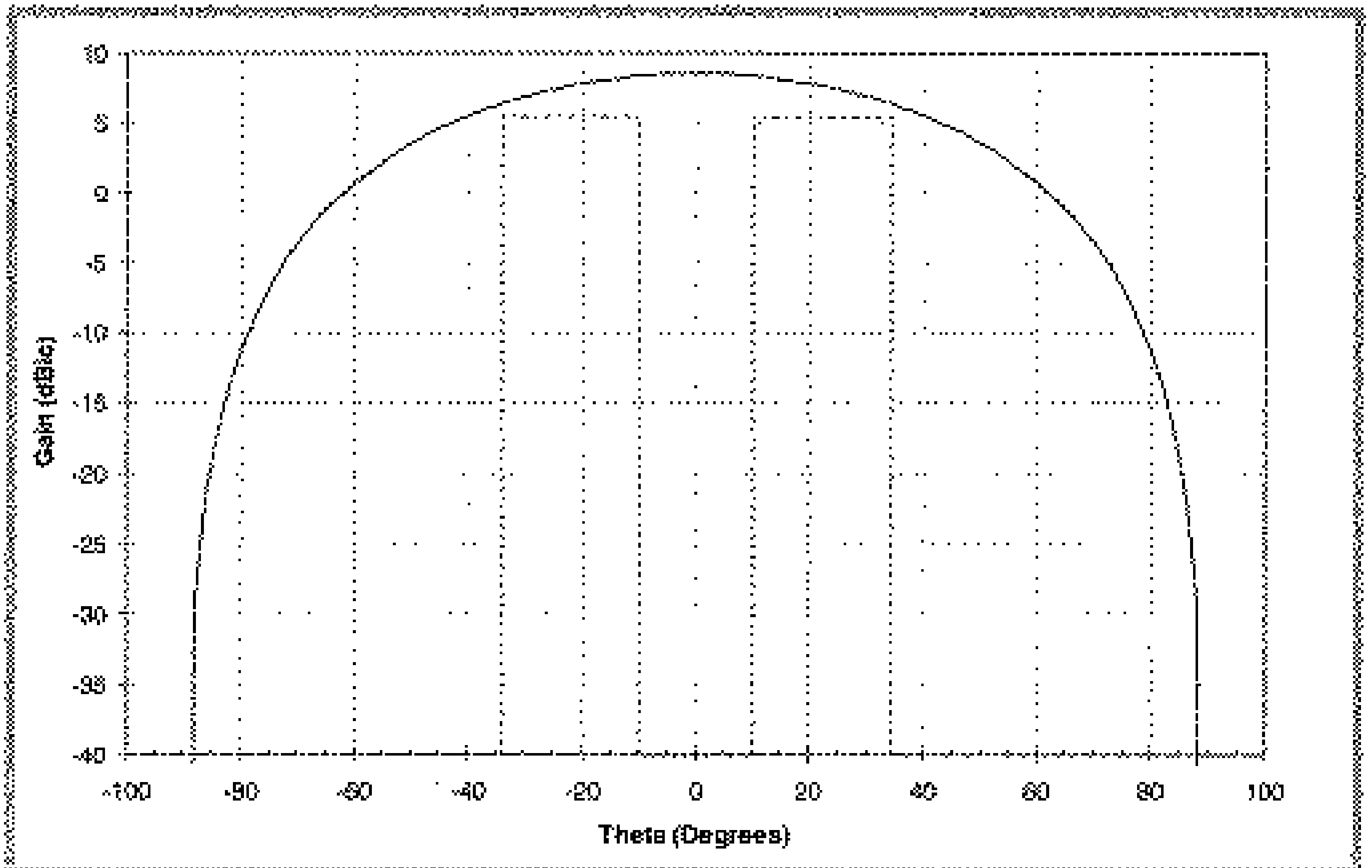
a = 0.86 in, or 0.88 in

r = 0.313 a

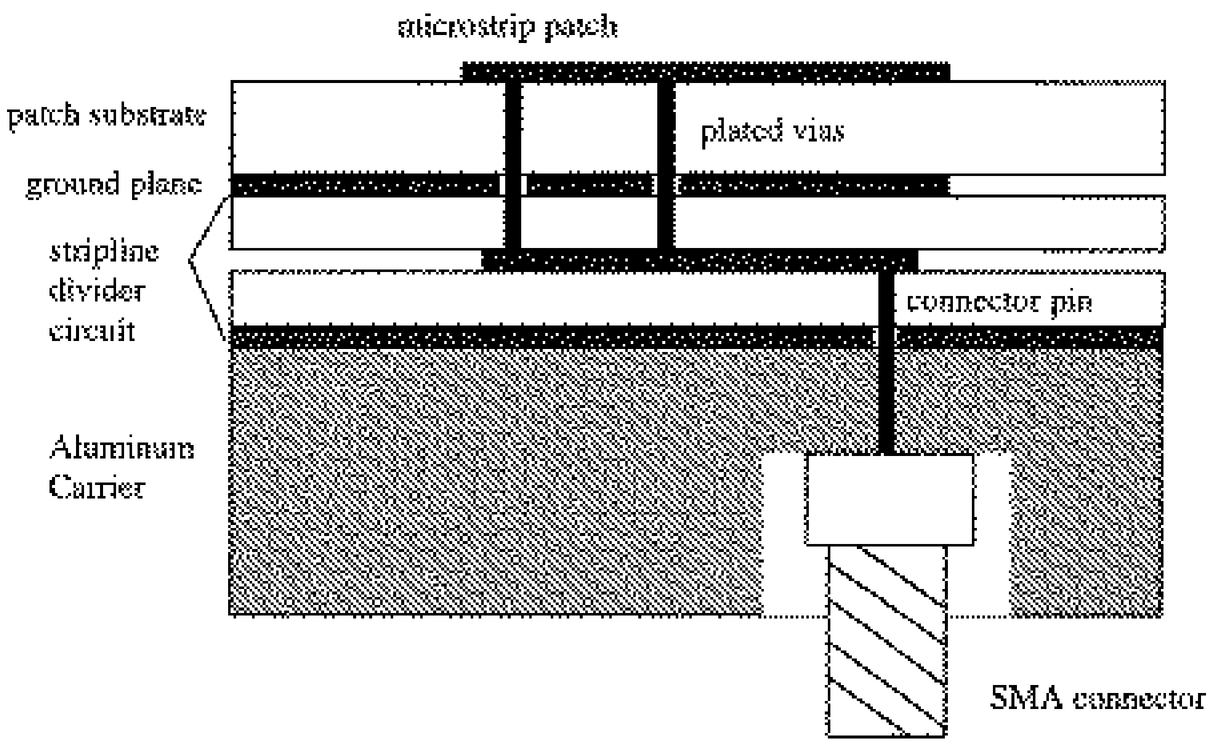
g = 0.3 λ

Medium Gain Antenna
Theoretical Pattern vs Requirements

C&DH, ACE & RF



Medium Gain Antenna Baseline Mechanical Configuration



Color Key:

white = Duroid

red = copper

shaded = Aluminum

Power Subsystem

Karen Castell

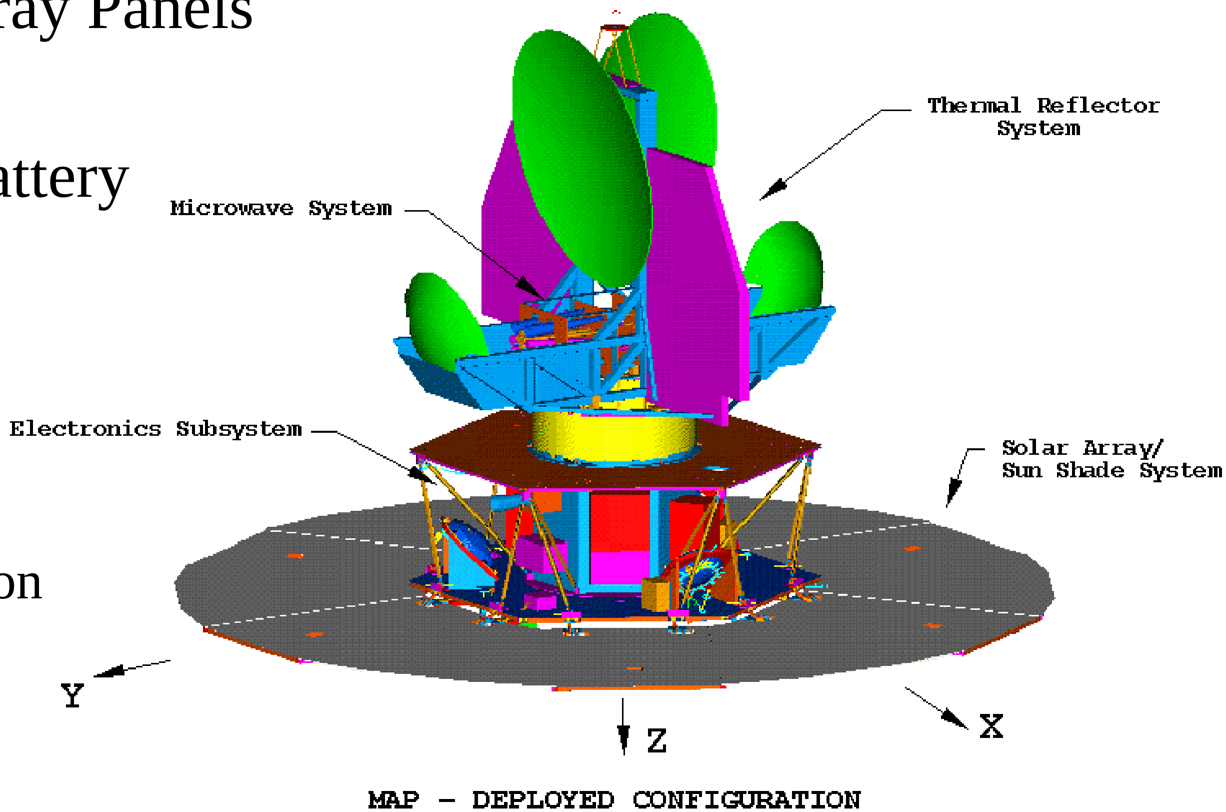
Amri Hernandez-Pellerano

Agenda

- Requirements
- Component Design
  - Solar Array
  - Battery
  - Power System Electronics
- System Analysis & Testing
- Verification Flow
- Copper Harness
- Schedule

Power System on MAP Structure

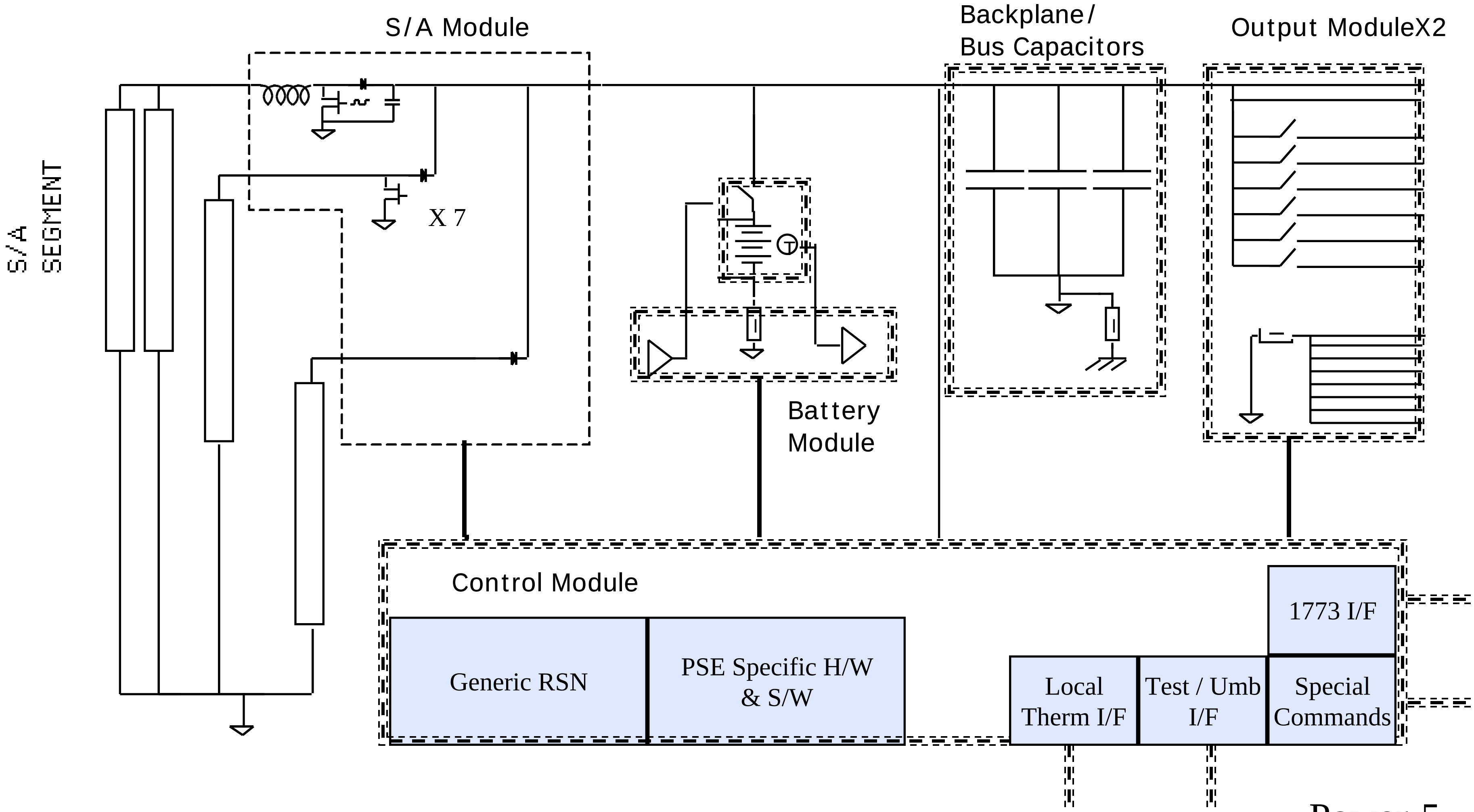
- 6 Identical Solar Array Panels
  - GaAs/Ge cells
- Nickel Hydrogen Battery
  - 23 Amp-hr
- PSE
  - Power Regulation
  - Charge Control
  - Switching/Distribution



Requirements

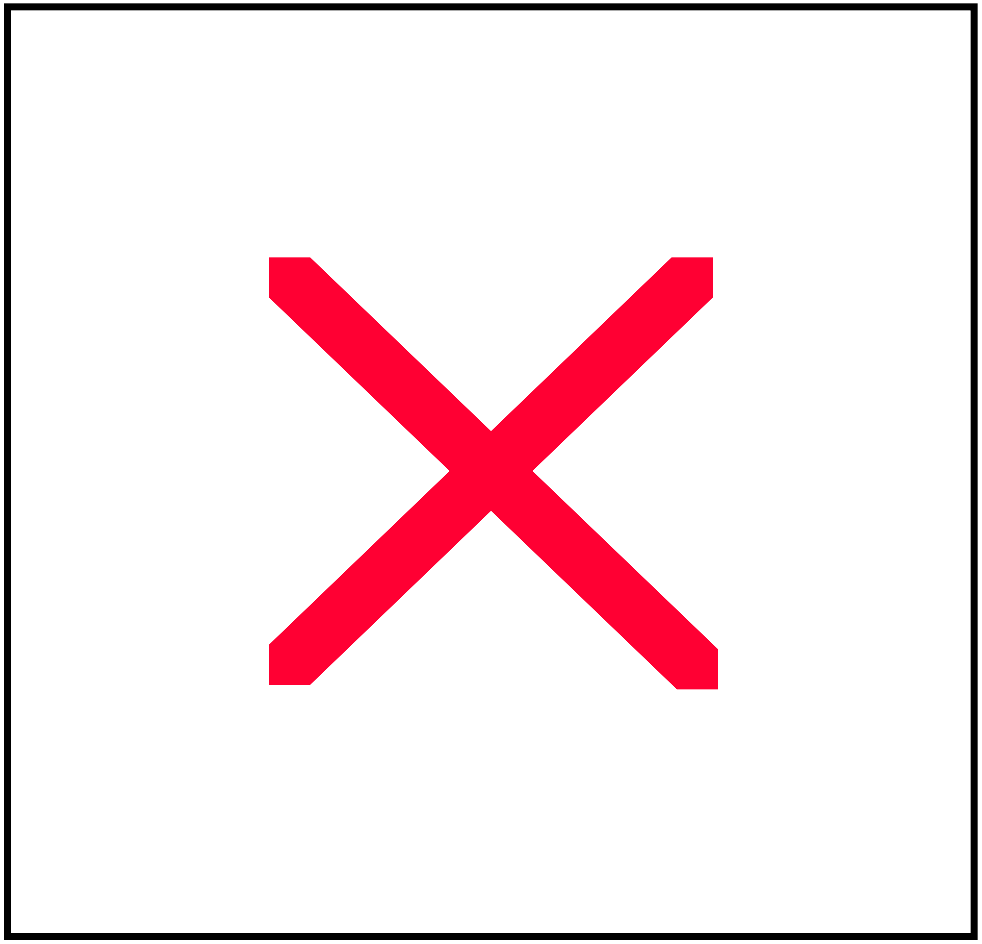
- Provide power to support all mission phases:
  - 400W Orbital Average at L2
  - 13 Amp-hrs during Launch Phase
  - 370W in Safehold
  - 400W in Maneuver Mode
- Provide Power Distribution and Switching to Subsystem and Instrument (28V+/- 7V)
- Provide Umbilical Signals
- 2 Special Commands- PSE RSN reset & C&DH LVPC reset
- Meet Electrical Specs
  - Bus Transients < 3V
  - Bus noise & ripple < 0.5V
  - Common Mode Noise < 100mV
  - Bus Voltage noise < 0.5Vp-p for 10Wp-p spin synchronous noise.

Power Subsystem Block Diagram



PSE Module Design Description

- **Solar Array Module**
  - Direct Energy Transfer
  - Non-dissipating Rad. Hard FETs
- **Battery Module**
  - DPC Interface
  - Any Battery Technology
- **Output Modules**
  - Solid State Overcurrent Protection
  - Current Sensing
- **Control Module**
  - RSN w/ Power System Functions
- **LVPC**
  - Overcurrent Protection
  - Modular Design



Solar Array Sizing Analysis

End of Life (27 months)

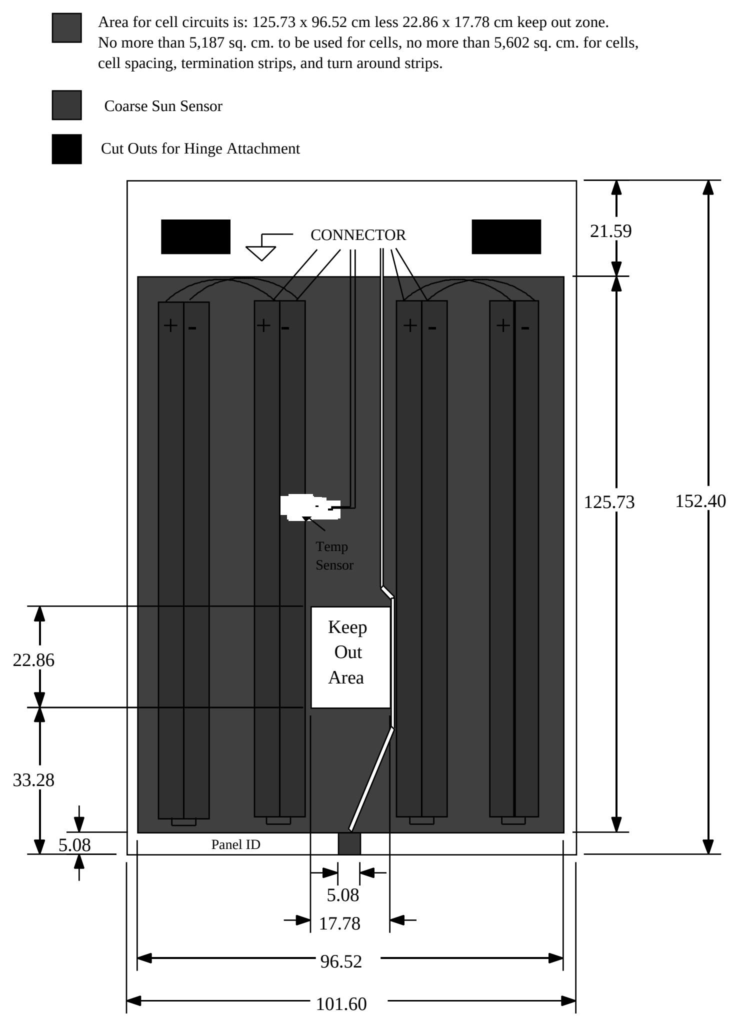
MAP SOLAR ARRAY SIZING

Nominal Eff:	18.5%		
Temp:	0.86	S/A Temp:	86°C
Assembly	0.98		
Charged Part:	0.93	Sun Angle	22.5°
UV	0.98		
Thermal Cycling	0.99		
L2 & Seasonal	0.95		
Micro Met	0.99	Effective Cell P	138 W/sq.m.
Random 1/24ckts	0.96		
Measurement	0.98	Required S/A P:	435 W
31.5V to 28V	0.89		
Cos Sun Angle	0.924		
Total loss Factor:	0.55		
Net Eff.	10.2%	Required Cell Area:	3.1sq.m.

- Simplified sizing analysis shows derivation of 3.1 square meters of solar cells. Note that this is actual solar cell area, not cell laydown area.
- Predicted array weight less substrate is 6.32 kg.

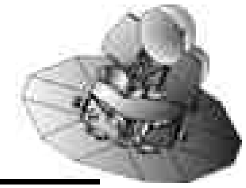
Solar Array Design

- 6 Identical Panels
- 12 Array circuits
- GaAs/Ge cells
- Silver Teflon between strings
- Thermal analysis predicts worst case temp of 86 C
- Cell array mass <7kg
- Verification:
  - Thermal/Vac (8 cycles)
  - Vibroacoustic
  - LAPSS (Hot Flash)



Battery Design

- 23 Amp-hr Nickel Hydrogen Common Pressure Vessel
  - Optimized for low mass
  - Cell Design Heritage from Mars Global Surveyor battery
  - PRT used for V/T control - 0.025 deg C/bit resolution
  - Thermistors for temp. sense - 0.04 deg C/bit resolution
  - Relay at the battery
  - Signal lines fused or buffered.
  - Charge control is V/T taper with fixed C/D ratio
    - BSOC resolution is 39 mA-msec/bit
- Verification
  - Qual. Battery tested to Qual. Levels
  - Flight tested to Acceptance levels



Nominal Operations

- Load Management
  - – Commands to Switch loads
  - – Current limiting
  - – Sensing
- Charge Control
  - – High rate charge
  - – V/T Taper Charge
    - Commanded V/T Level
  - – Trickle Charge
    - Calculated SOC with Commanded C/D Ratio

Contingency Operations

- Contingency / Protection
  - Overvoltage
  - Undervoltage
  - Overcurrent
  - Low State of Charge
  - High Delta Half Voltage
  - High Temperature

PSE ETU Testing Results

Power Subsystem

Requirement	Test Results	Comments
Load Transients<3V	2.24V	Instrument, 150W
	1.48V	S/A segment
Bus Noise<0.5Vp-p	0.178V	Ripple noise, 125kHz.
Spin Noise<0.5Vp-p w/10W load var.	0.074V	

Tests Completed

✓Bus Ripple
✓Bus Transients
✓Bus Impedance
✓Commandability
✓Telemetry Verification and Calibration
✓Software Control Loop Operation
✓Power System Operational Modes
✓Full Power Transfer- All Modes
✓LVPC Functional and Performance
✓PSE Module Functional and Performance
✓Spin Rate Noise

Tests Completed, Continued

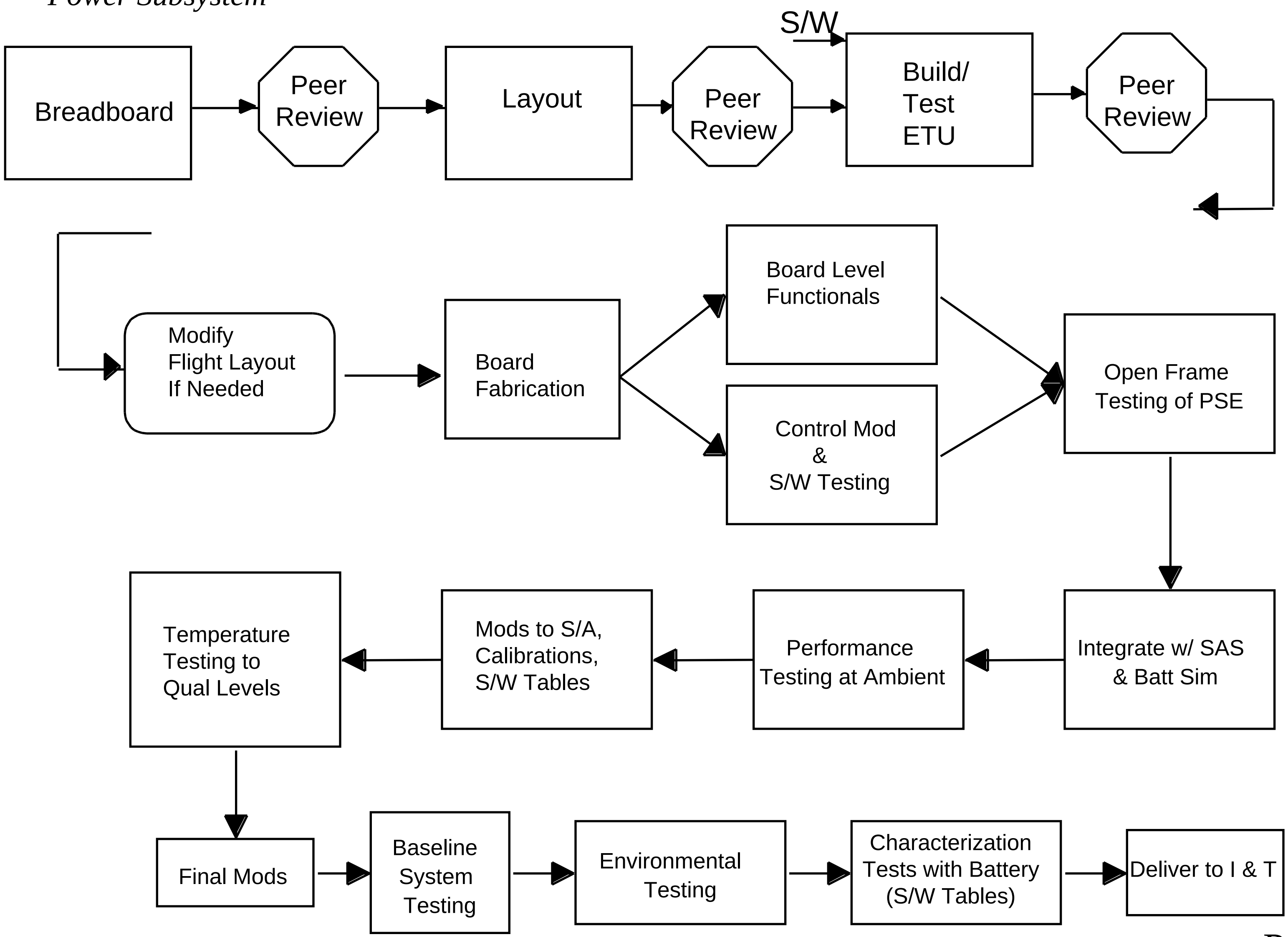
✓Software FDC
✓Transients with Software Control Disabled
✓Loop Phase/Gain Measurements

Tests to be Completed

Common Mode Test
EMI
Temperature Testing
Verification with Real Battery

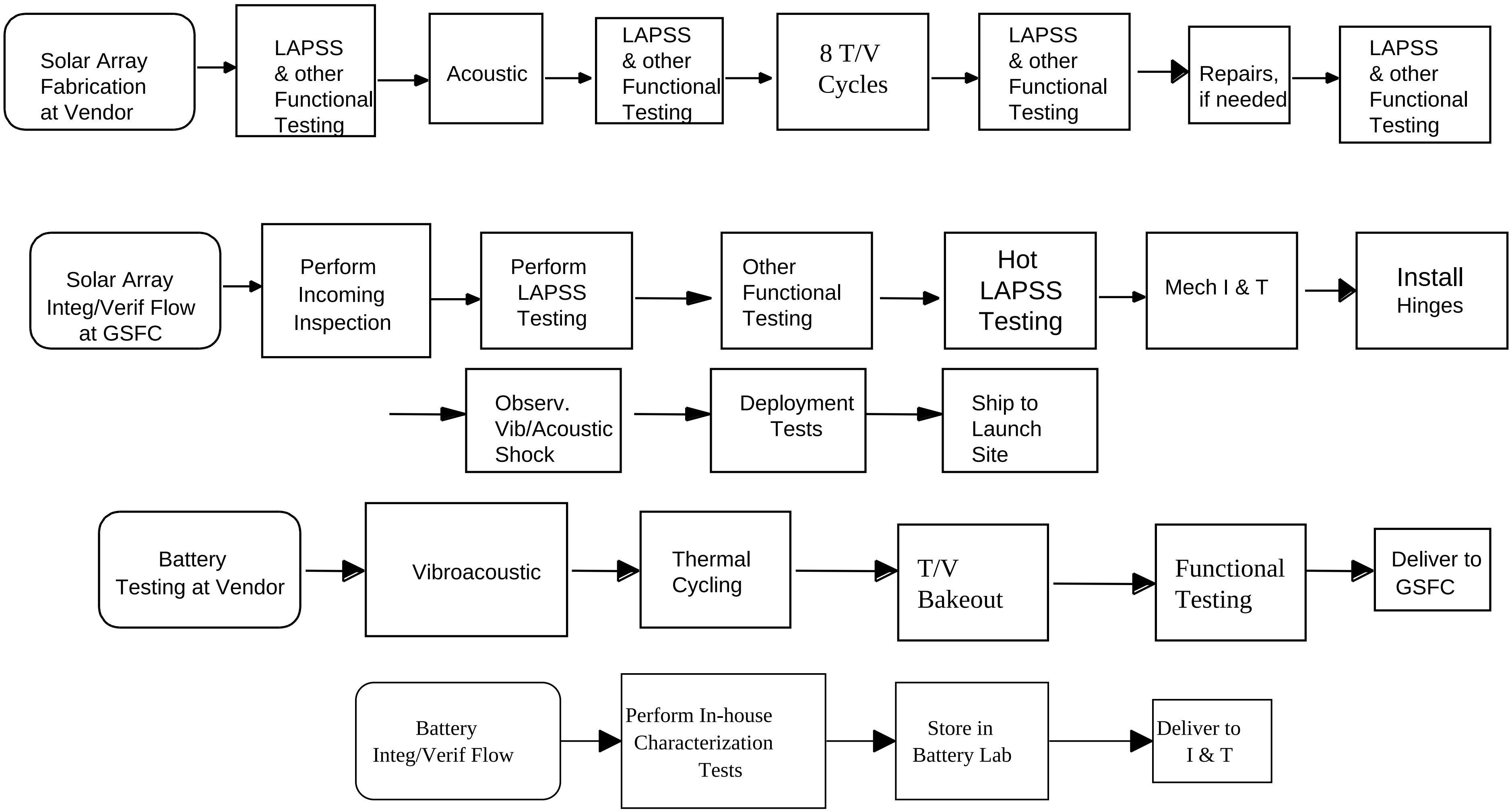
PSE Verification Flow

Power Subsystem

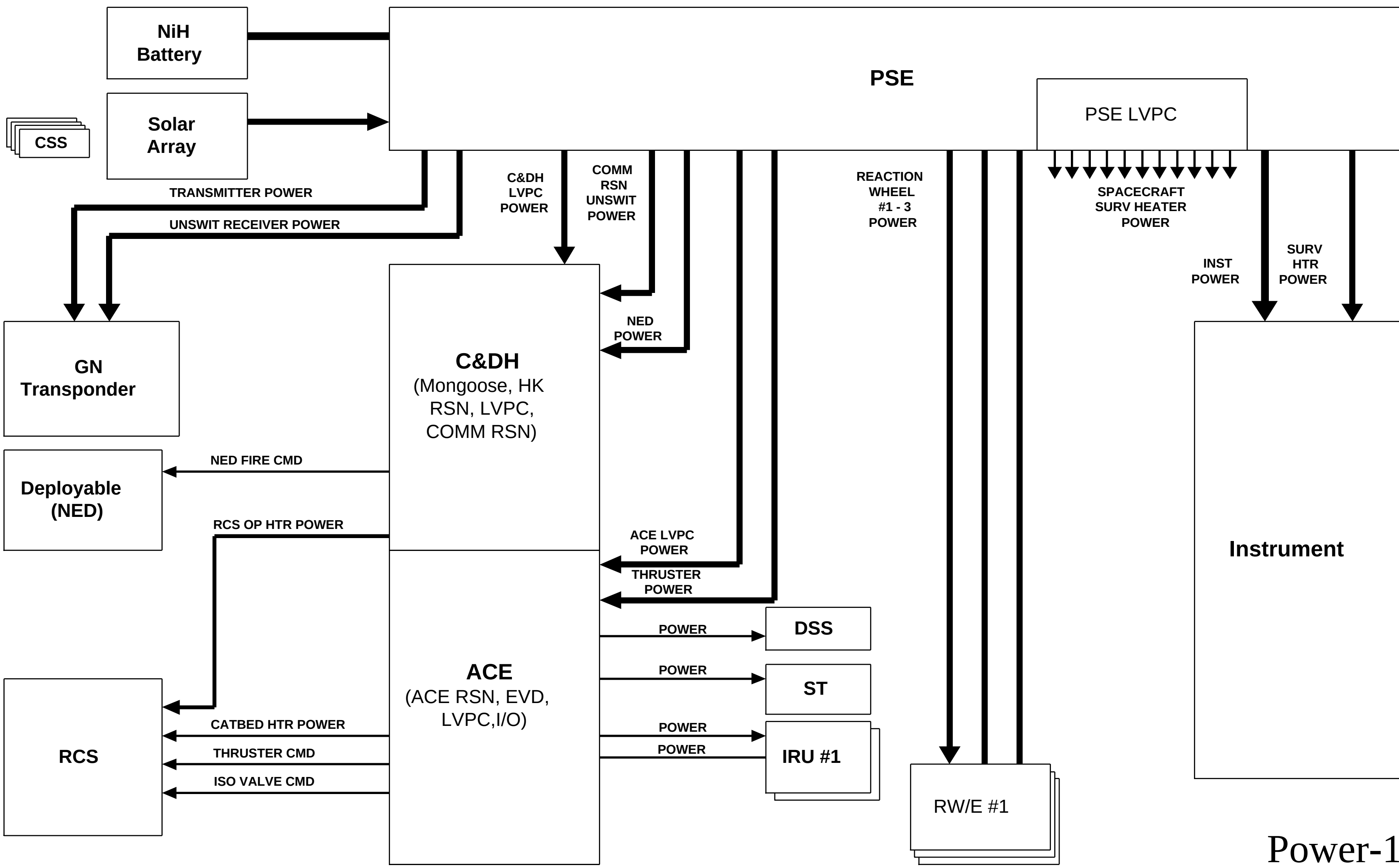


Component Verification Flow

Power Subsystem



MAP System Interconnect Diagram



Copper Harness Design

- Requirement Sources
  - Electrical Systems Specifications
    - Grounding, etc…
  - Components Requirement Documents and ICD’s
    - Pinouts, constraints
  - Performance Assurance Requirements
  - Mfg., Inspection
  - PPL Derating Guidelines
- Define special grounding and shielding requirements.
- Define cable bundling by collecting or separating signals as appropriate.
  - Sensitive Instrument Lines
  - Primary Power Lines
- Terminate shield grounds at the source.

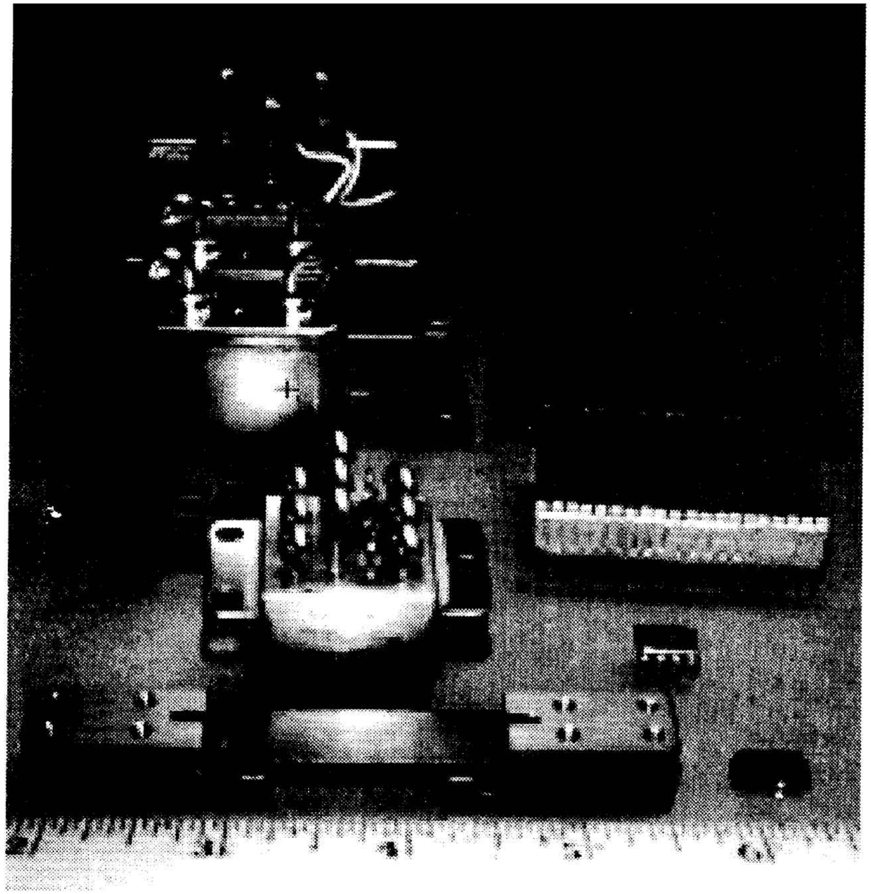
Process for Fabrication and Testing

- Develop Harness on mock-up (“HEXSAT”).
- Fabrication requirements to the guidelines of the NHB’s.
- Add strain-relief for 2 reworks.
- Protect all unfused power wiring from shorts due to handling
- Most rectangular ‘D’ connectors shall be potted.
- Transfer Harness to Flight Structure
- Testing
  - Continuity & Isolation
  - Insulation Resistance
  - Special Testing
    - 1773 Loss and Margin Testing of S/C Fiber Bus

Power System Conclusions

- Battery contract awarded. Cell design heritage..
- Solar Array contract to be awarded this month.
- PSE Testing shows margins in meeting all requirements.
- Flight changes ready to implement.

Old versus New Technology



Volume Reduction: 86%

Weight Reduction: 78%

Verification Matrix

Power Subsystem

Paragraph Number	Description	Component Level	Subsystem Level	Spacecraft Level
	Functional Requirements			
3.1	Observatory load, Bus voltage, mission life.	A,T	A,T	A,T
3.1.1	Launch/deployment	N/A	N/A	A
3.1.2	Safehold	N/A	N/A	A
3.1.3	Maneuver Mode	A,T	A,T	A,T
3.1.4	Observing Mode	A,T	A,T	A,T
3.2.1.2	Functional- I/F to S/C, Battery charge, Sp. cmd	A,T,I	A,T	A,T
3.2.2	Solar Array- BOL, EOL power, voltage output	A,T	A,T	A
3.2.3	PSE- Bus voltage, shunt reg, , charge control	A,T,I	A,T	A,T
3.2.4	Battery- 300 W-hr, 60% DOD	I,T	T	T
3.2.5	Single Point Failures - Critical Redundancy	A,T	A,T	A,T
3.2.6	Test Connector Signals - PSE/Battery	I,T	T	T
	Performance Requirements			
3.3.1.1	PS Output Voltage	A,T	A,T	T
3.3.1.2	Observing Mode, Launch Mode Power Output	A,T	A,T	A,T
3.3.1.3	Output Impedance	A,T	A,T	A
3.3.1.4	Voltage transients	A,T	A,T	A
3.3.1.5	Output ripple	A	A	N/A
3.3.1.5.1	Spin Synchronous Noise	A,T	A,T	A,T
3.3.1.6	Battery recharge capability	A	A,T	A,T
3.3.1.7.1	Bus & battery fault detection software	A,T	A,T	A,T
3.3.1.7.2	Bus & battery fault detection hardware	A,T	A,T	A,T

A=analysis, I=inspection (visual), T=test, N/A = not applicable

Operations

Unswitched Loads:
- TDRS Receiver Converter
- TDRS Transponder RSN

Loads Powered on at Power up (Default):
- ACE LVPC (EVD Logic)
- C&DH LVPC
- Transmitter 1&2
- Reaction Wheels
- S/A Deployment Actuators
- EVD

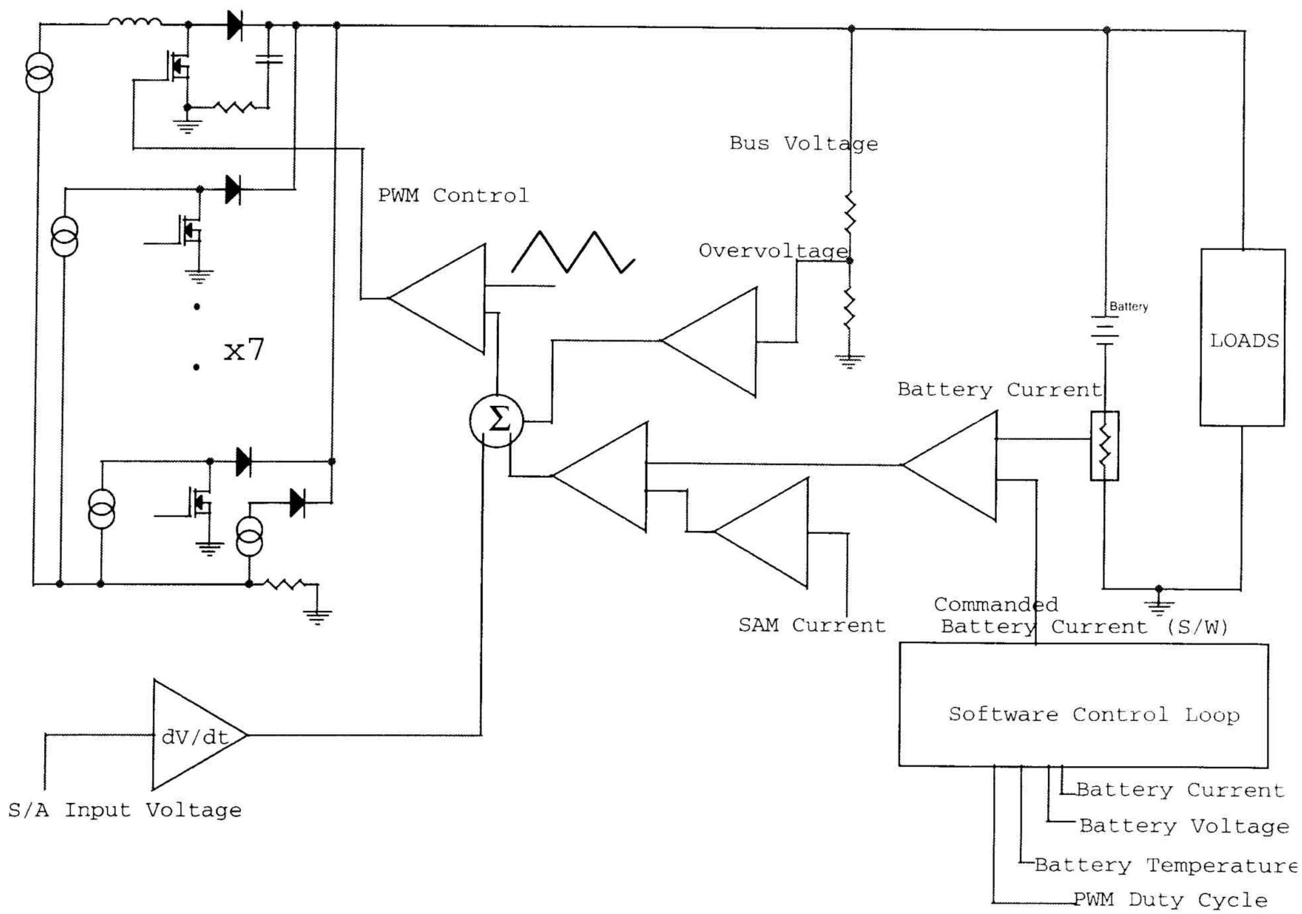
Loads Default OFF:
- Instrument
- Survival Heaters

Contingency Operations

Power Subsystem

Condition	**Method**	**Resultant Operation**	**Comments**
Bus Overvoltage	H/W	Shunt array segments	SAM ladder
	S/W	Shunt array segments	S/W limit < H/W.
Bus Undervoltage	S/W	Load shed, unshunt array	
Bus Overcurrent	H/W	Load shed	SSPC circuit break.
	S/W	Load shed, Shunt array	S/W limit < H/W.
Bus Undercurrent	S/W	Unshunt array	
Battery Overcurrent	S/W	Shunt array	Charge current.
Battery SOC low	S/W	Load shed, unshunt array	
Battery Delta Half High	S/W	Load shed, trickle charge	
Battery Overtemperature	S/W	Load shed, trickle charge	
No control signal to SAM	H/W	Unshunt array	32 second watchdog.

Control Loop Block Diagram



PSE SAM Regulator

- Outer Loop

  Software control signal

  Battery Current

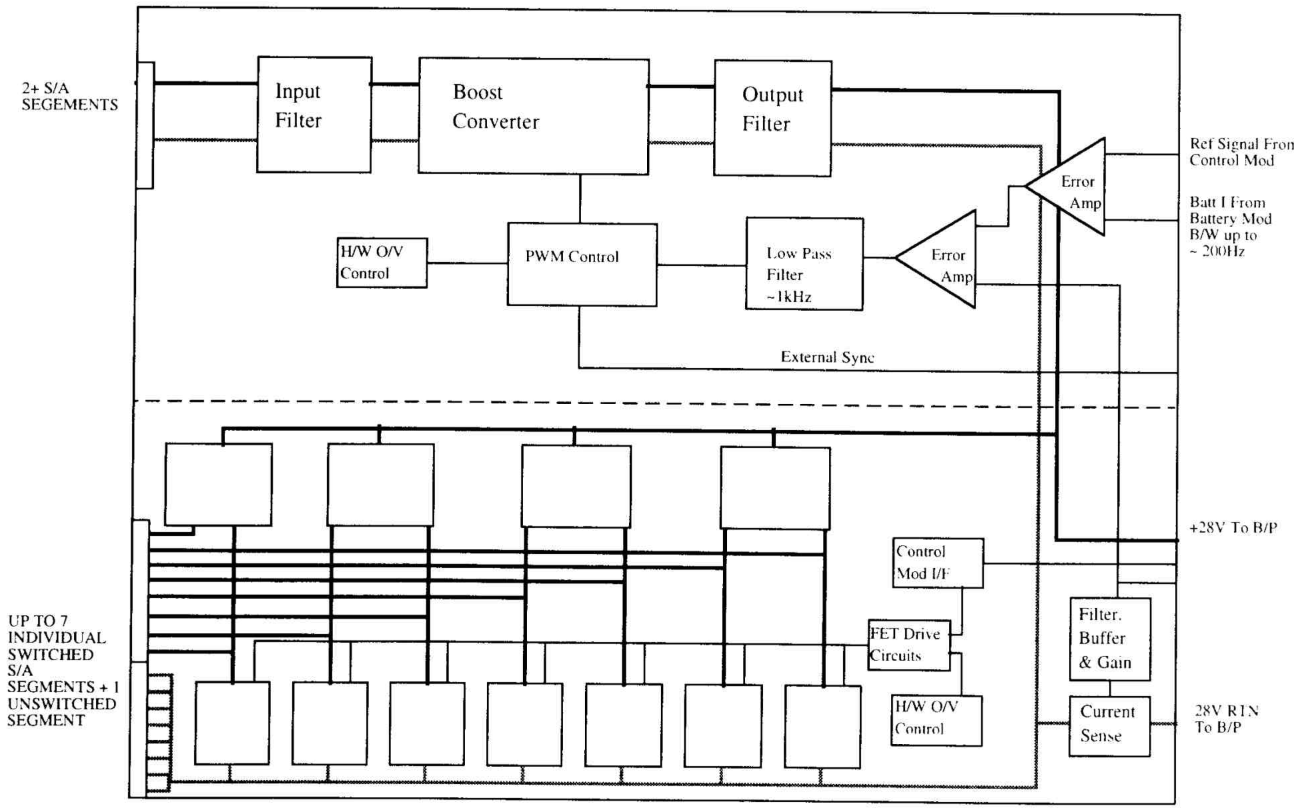
  Phase/Gain Margins = 89 deg/ 24 dB

- Current Mode Control Inner Loop

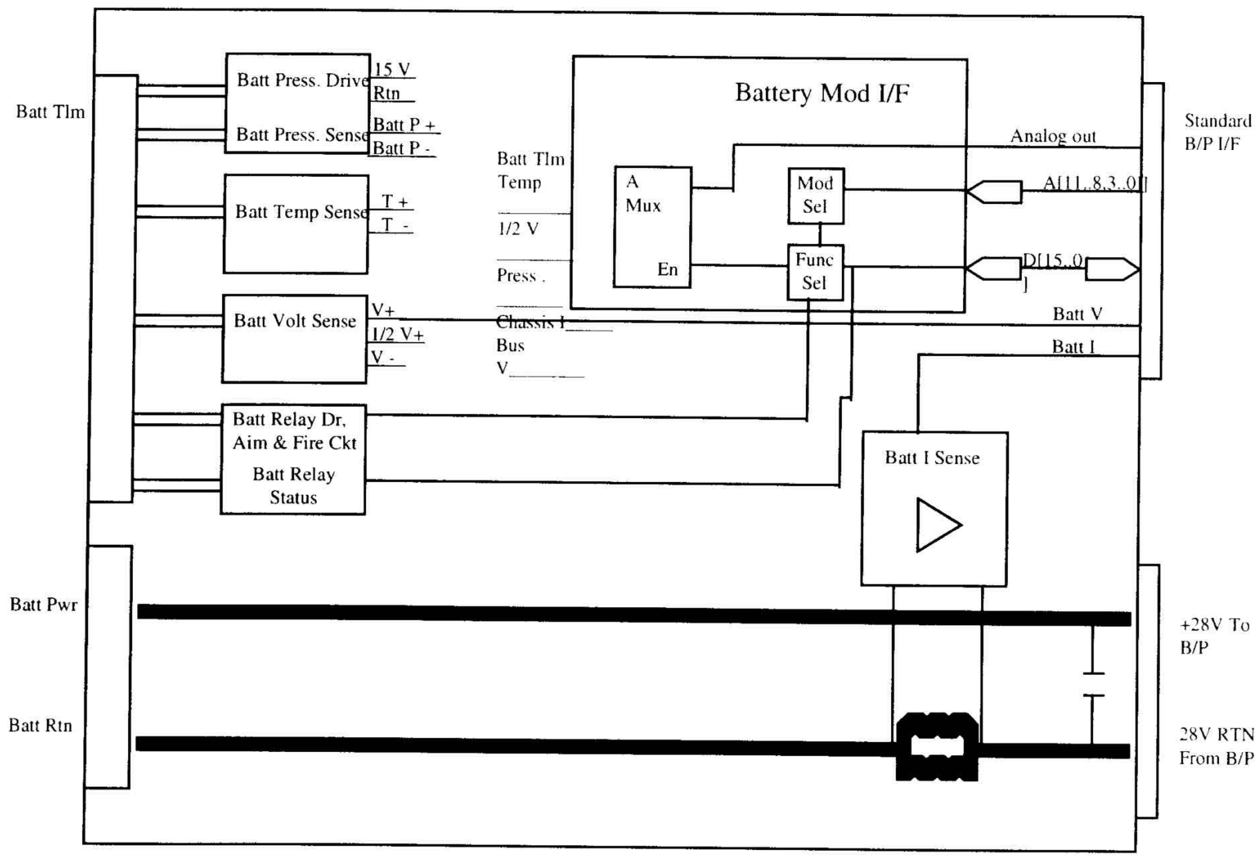
  SAM Current

  Phase/Gain Margins = 68 deg/26 dB

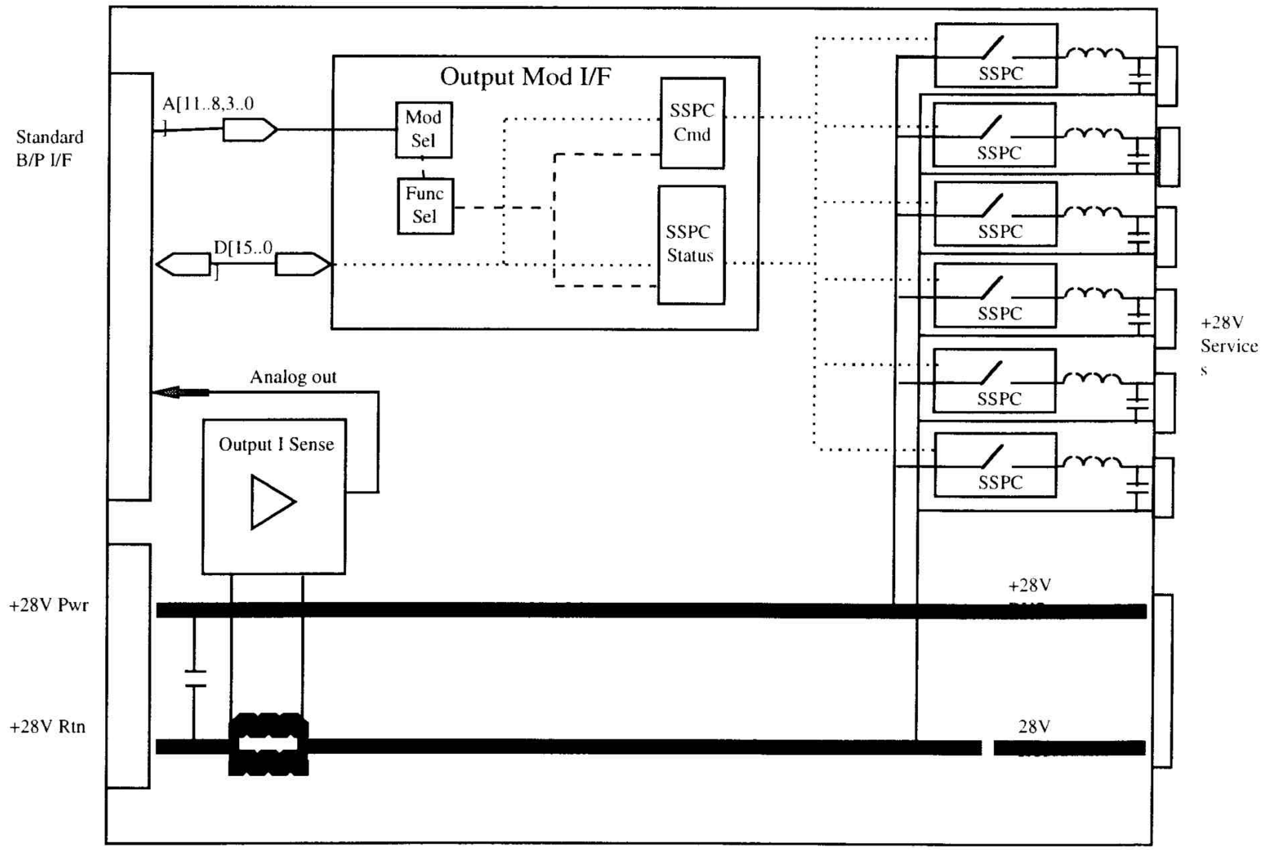
Solar Array Module



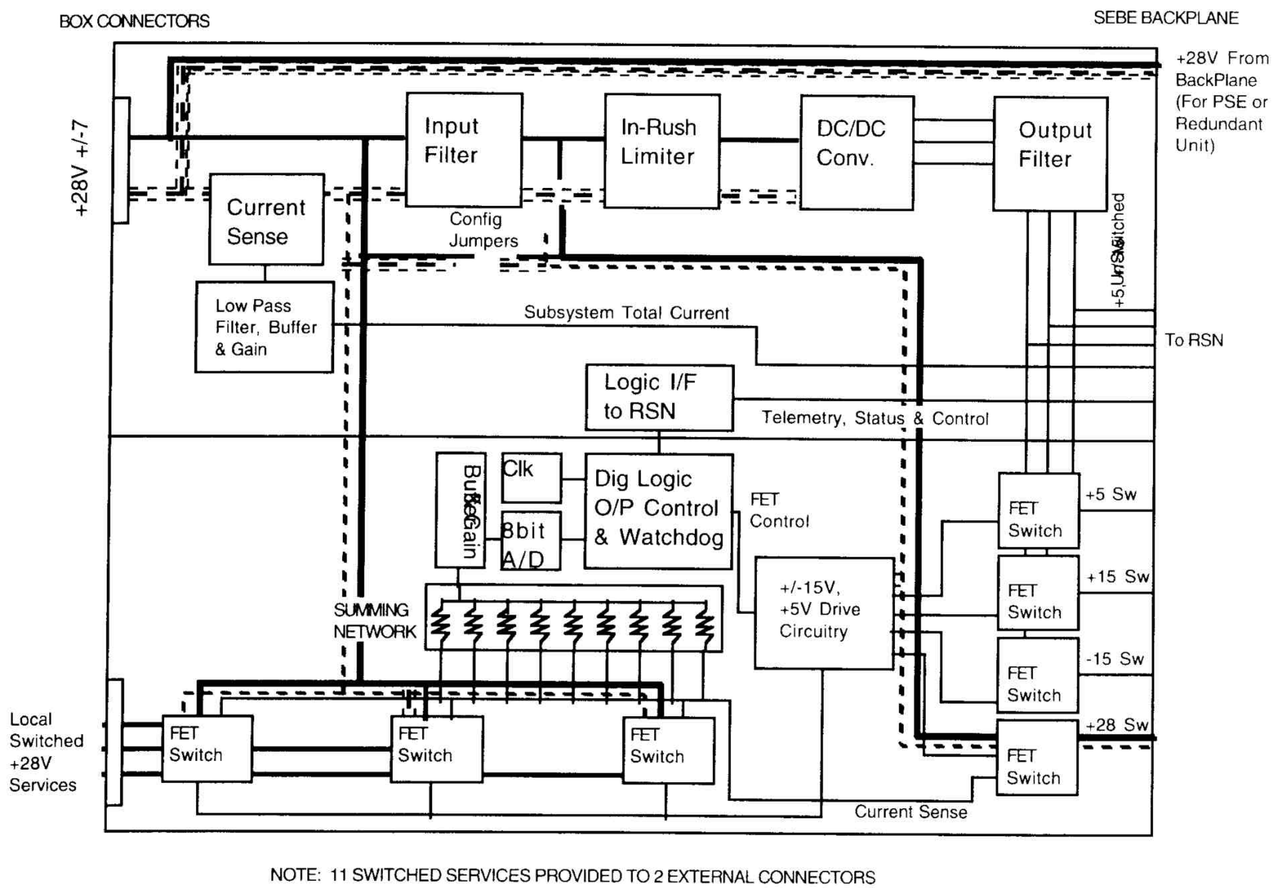
Battery Module



Output Module



Low Voltage Power Converter



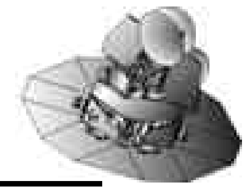
Power Subsystem Mass Estimate

- Battery Mass: 21.7kg.
- Solar Array Cells: 8.04kg.
- PSE Mass Measurements (g):
  - With 2 Output Modules

Housing		3600
Modules		9777
	LVPC	942
	S/A	1330
	Control	900
	Output1	1770
	Output2	1770
	Battery	1165
	Backplane	1900
Conf Coating		350
Total		13727
Requirement		18000
Margin		4273

PSE Power Summary

Box Power Consumption			Box Power Dissipation
			MAP Avg
Control Mod:	GenRSN:	2.6	2.6
	Other PSE	1.7	1.7
SAM:		2.4	11.4
Output (x2):		3.0	5.0
Batt:		0.8	0.8
LVPC:	Converters	2.3	2.3
Total		15.8W	23.8W
Requirement		16.0W	
Margin		0.2W	



Microwave Anisotropy Probe
Attitude Control System

David Ward

May 18, 1997

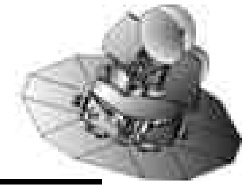
Agenda

- Requirements
- Subsystem Design
- Components
- Analysis
- Verification
- Conclusions

Requirements

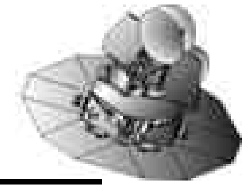
- Perform an all-sky scan
  - Compound spin at a 22.5° (± 0.25°) offset to anti-sunline
  - 2.78 °/s ± 5% spin
  - 0.1 °/s ± 5% precession
- Mission orbit is L2
  - Perform phasing loop Delta V to get there:
    - Thrust along velocity vector ± 5°
    - ACS maneuver accuracy: 1%
  - Do stationkeeping while there:
    - Maintain 20° (± 5°) offset to anti-sunline
    - Ability to get Delta V in any direction
  - Manage momentum throughout the mission:
    - Unloading to 0.3 Nms/axis

Requirements (continued)



- Perform on-orbit attitude determination
  - – Observing operations requirement is 1.3 arcminutes, one sigma, relative to ACS internal errors only
  - – Also must perform sufficient attitude determination to meet control mode pointing requirements
- Acquire power-positive attitudes upon launch separation and in the event of anomalies
  - – Acquire from launch separation initial conditions:
    - ±2 °/s X and Y tip-off rates, ±2 RPM Z axis rates
    - 35 minutes to complete acquisition to within 25°
  - – Acquire on wheels alone for up to 2 sigma rates
  - – Maintain an independent SafeHold

MAP ACS Summary Chart



Science Mode Pointing

- Zero-momentum COBE-type control
- Spacecraft spin rate: 2.78 °/s;
  Precession rate: 0.1 °/s;
  Pitch offset: 22.5° +/- 0.25°
- Maps the entire celestial sphere twice in one year

Orbit

- Earth-sun L2 point, to minimize environmental disturbances to instrument
- Lunar assist injection, requiring 80m/s delta V from spacecraft RCS (85 minute burns)
- Stationkeeping to maintain 1° to 10° Lissajous orbit
- Lack of magnetics requires thruster-based momentum unloading

Architecture

- Mongoose V processor, 1773 data bus, using ACE for sensor/actuator interfaces
- Distributed power switching, housekeeping

Attitude Determination

- On-board, using Kalman Filter processing of ST, DSS, IRU
- ACS on-orbit allocation: 1.3 arcmin, RMS

SafeHold

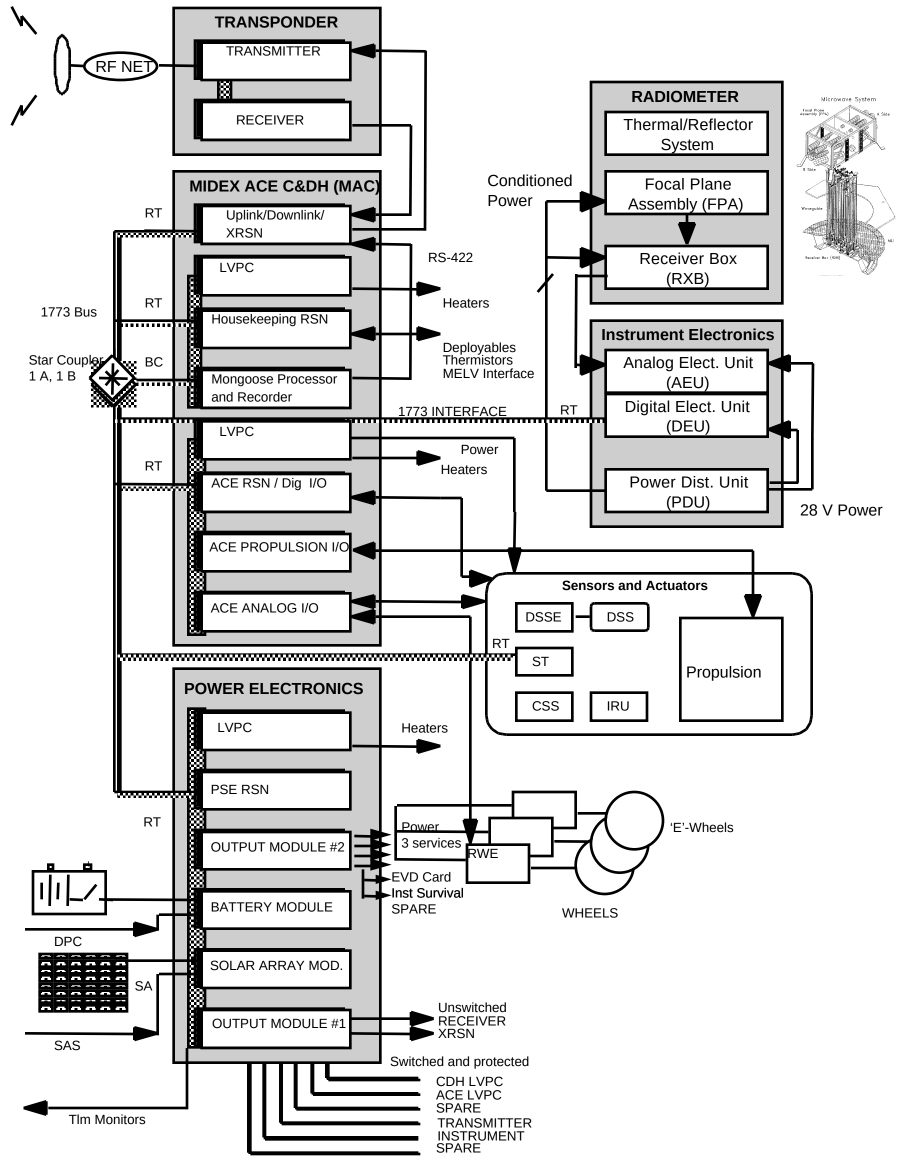
- Maintained in ACE, independent from primary control algorithm
- Uses CSS, RWAs and optionally IRU
- Acquires sun within 25° in 35 minutes

Sensor/Actuator Complement

- Lockheed AST 201 Star Tracker
- Two Kearfott TARA Inertial Reference Unit
- Adcole 64°X64° Digital Sun Sensor
- Six Adcole Coarse Sun Sensors
- Three Ithaco E-Reaction Wheels
- Six 1lb. Thrusters
- MIDEX Attitude Control Electronics

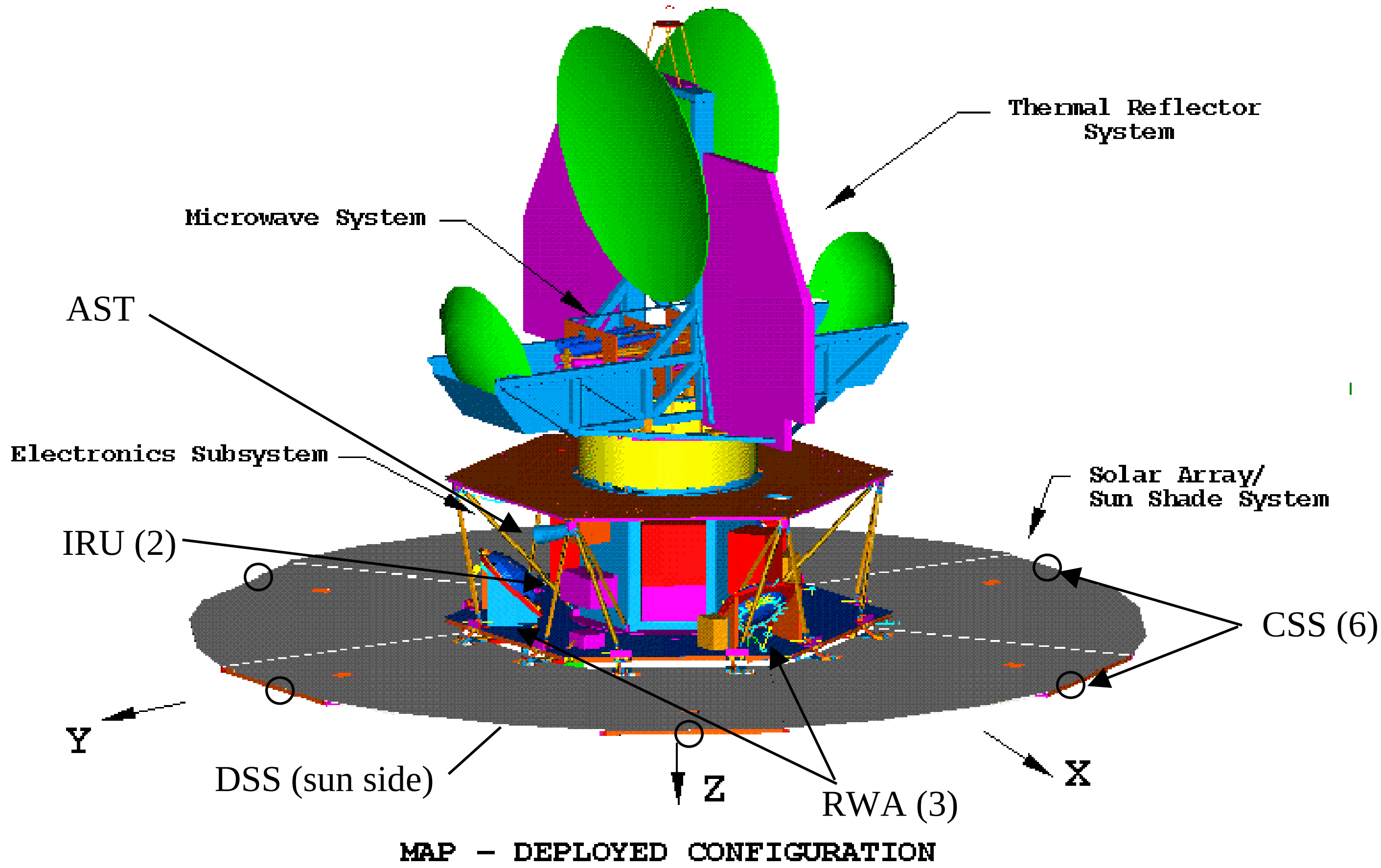
MAP Architecture

Attitude Control

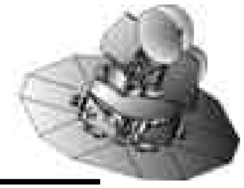


MAP Spacecraft

Attitude Control

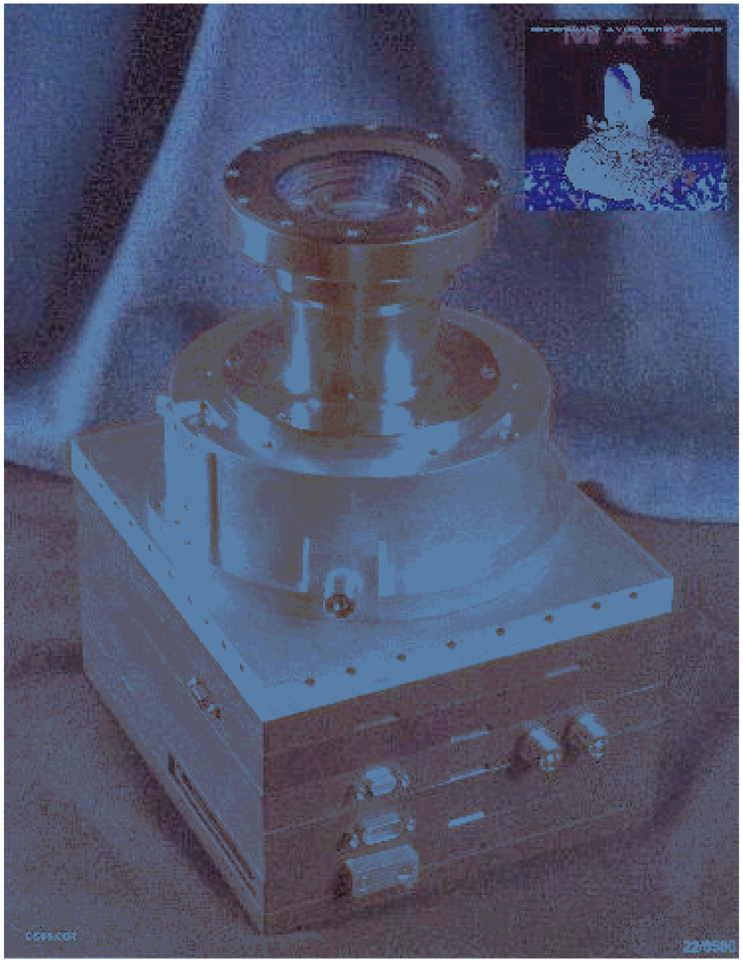


Star Sensor (AST)



- Vendor/Design: Lockheed Martin AST 201
- Other Users: Image (1/00), EO-1 (5/99)
- Modifications: Time Delay Integration (TDI), AS1773
- Data: Two AS1773 packets, Quaternion output
- Performance:
  - Tracking rate: 3 °/s
  - Accuracy: 2.3 arcsec, P/Y, 21 arcsec, Roll (peak)
  - NEA: 1.5 arc, P/Y, 24 arcsec, Roll (one sigma)
- Verification: Standard MIDEX protoflight testing

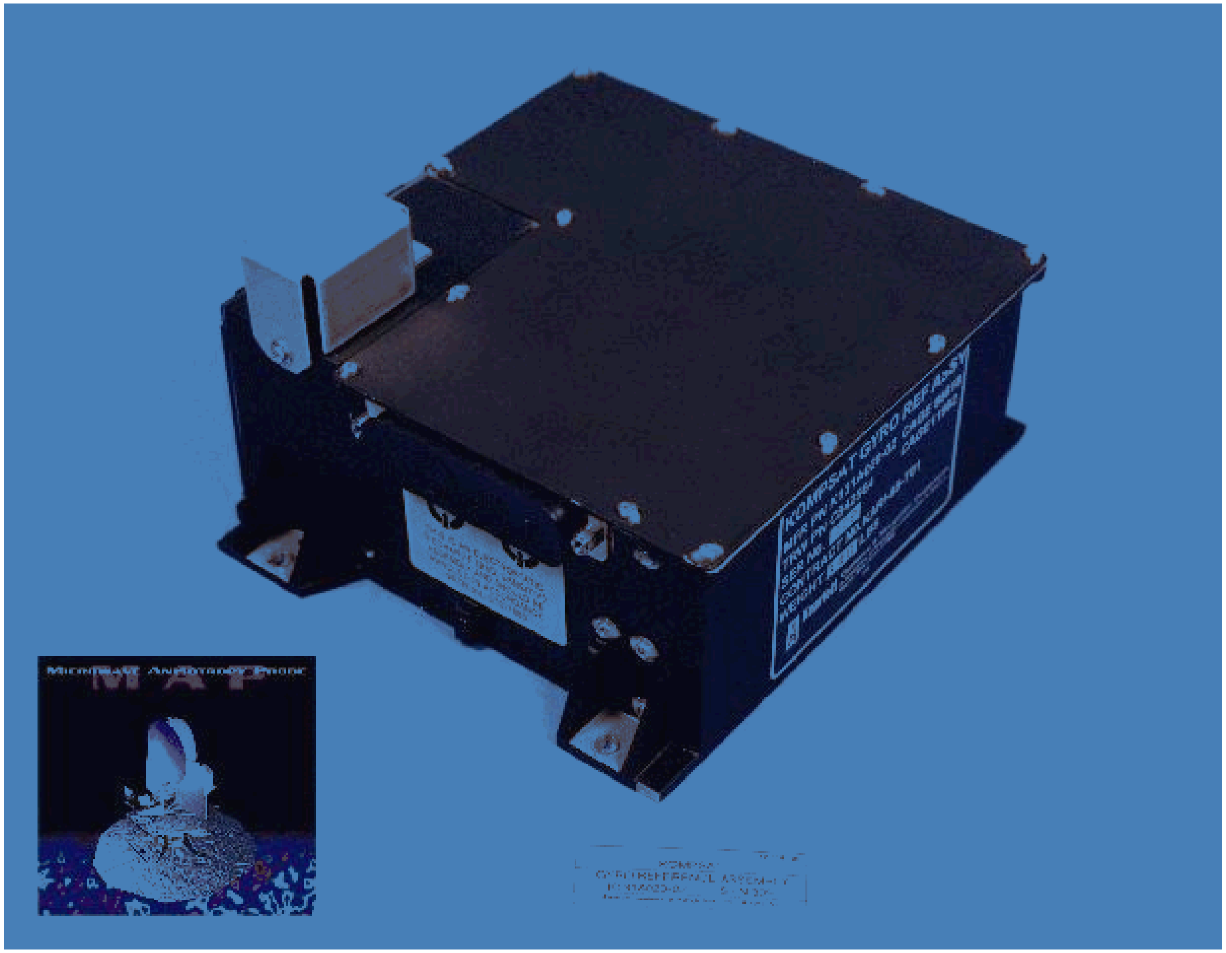
Star Sensor



Inertial Reference Units (IRU)

- Vendor/Design: Two Kearfott TARAs (4 axes sensed)
- Heritage: TOMS-EP
- Modifications: 12 °/s rate range
- Data: Digital pulse train, analog housekeeping
- Performance:
  - Quantization: 1 arcsecond/pulse
  - Linear range: ± 5 °/s
  - Angle random walk: <0.03 degrees/root-hour
- Verification: Standard MIDEX protoflight testing, EMI/EMC on first unit only

Inertial Reference Unit



Digital Sun Sensor (DSS)

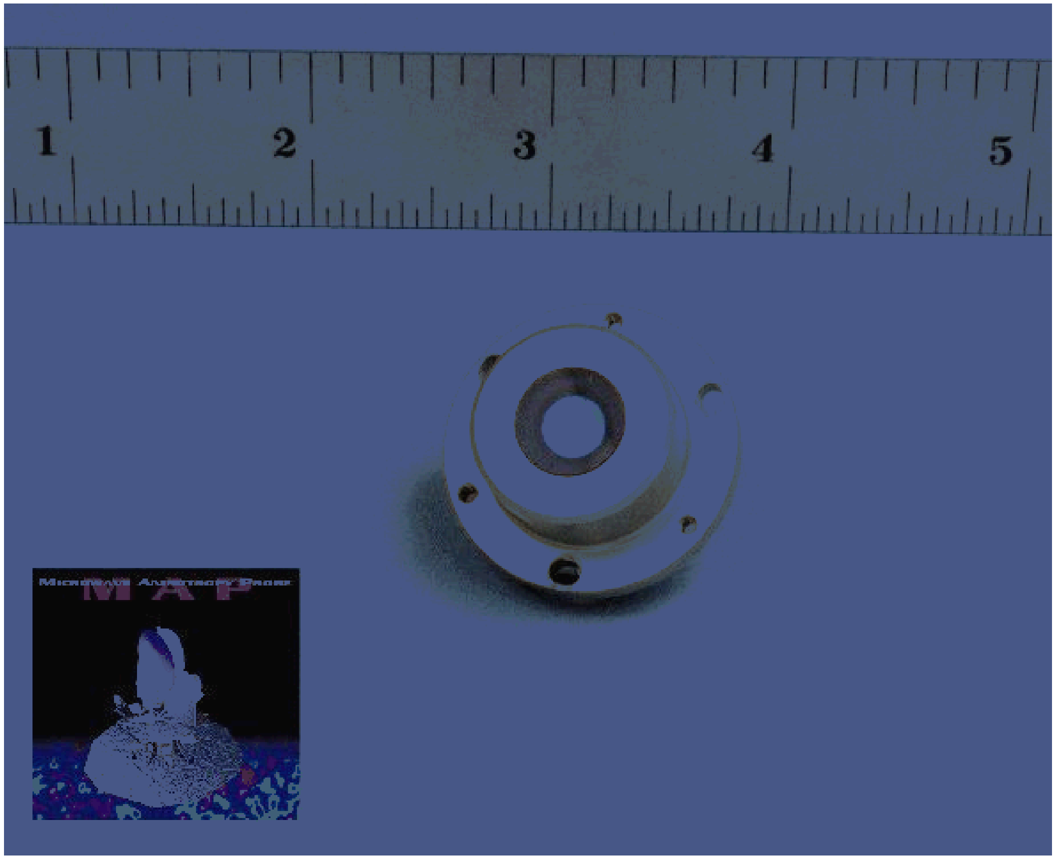
- Vendor/Design: Adcole high performance DFSS
- Heritage: XTE (T-V qualification)
- Modifications: None
- Data: Two serial digital words, analog housekeeping
- Performance:
  - Field of view: ± 32°
  - Resolution: 0.004 ° (0.24 arc min)
  - Accuracy: 0.017 °
- Verification: Standard MIDEX protoflight testing, acceptance temperatures in T-V

Digital Sun Sensor

Coarse Sun Sensors (CSS)

- Vendor/Design: Adcole CSS
- Heritage: SAMPEX (qualification)
- Modifications: None
- Data: Photoelectric current
- Performance:
  - Field of view: ± 80°
  - Accuracy: 10° (matched set)
- Verification: Standard SMEX acceptance testing (vibration and temperature levels same as MIDEX)

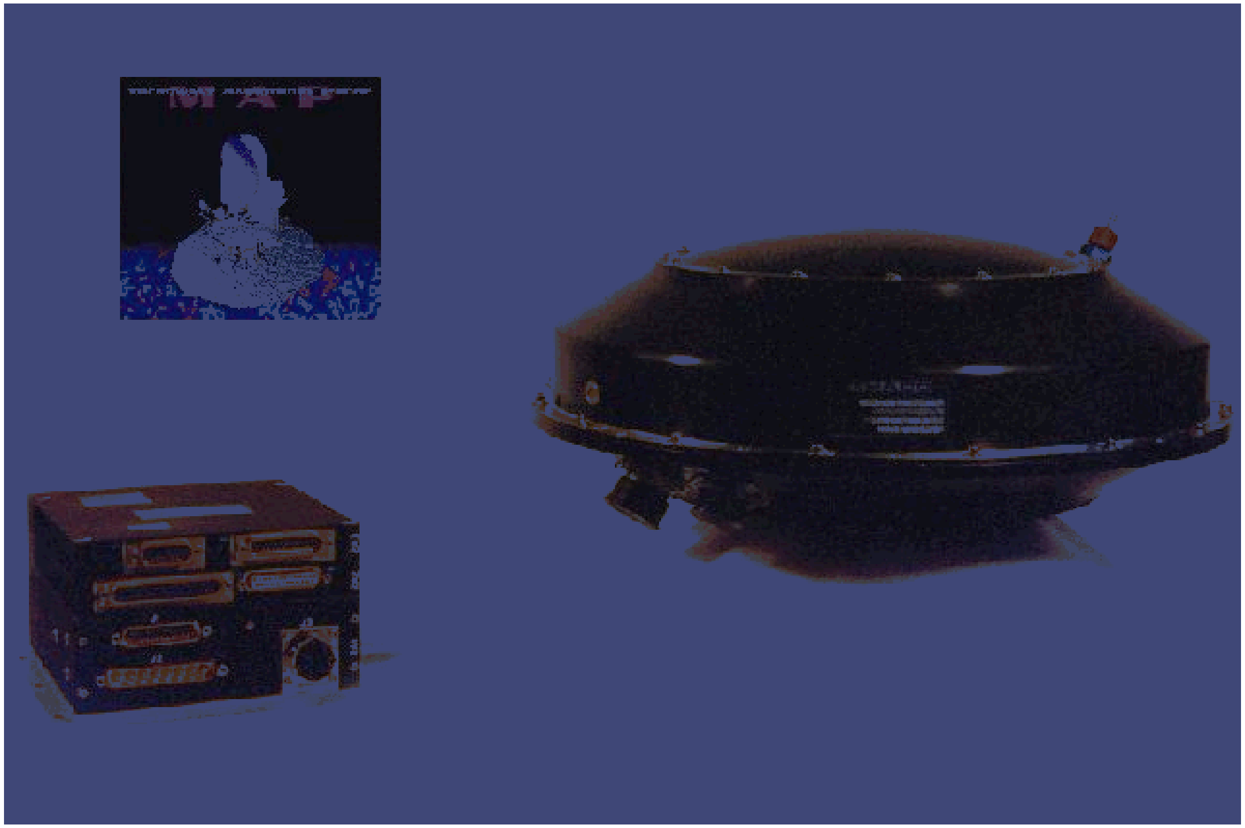
Coarse Sun Sensor



Reaction Wheels (RWA)

- Vendor/Design: Ithaco E Wheels
- Heritage: TRMM (qualification, ongoing life test)
- Modifications: None
- Data Interface: Analog torque input, tach output
- Performance:
  - Reaction Torque: ±0.1 Nm
  - Momentum Storage: ± 75 Nms
- Torque command limited in Attitude Control Electronics
- Verification: Standard MIDEX acceptance testing, EMI/EMC on first unit only, sine vibration to protoflight levels

Reaction Wheels

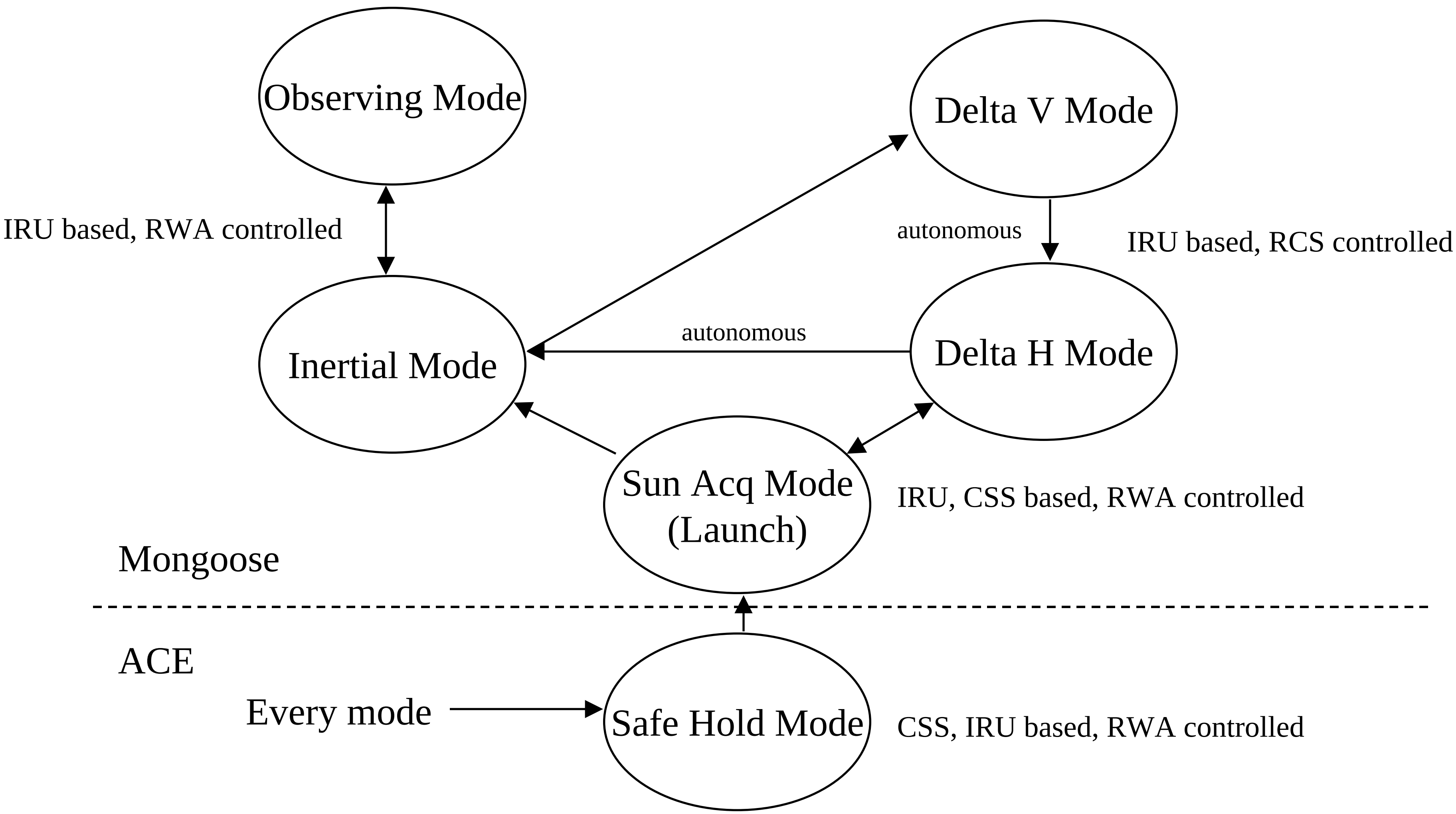


Analysis Overview

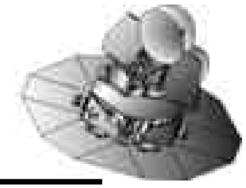
- All control modes simulated and tested in high fidelity simulation (HiFi)
  - All modes meet their derived performance requirements with margin given anticipated component performance
- Linear stability analysis shows adequate robustness
- Covariance analysis shows excellent attitude determination performance

Mode Diagram

Attitude Control

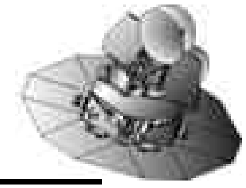


Mode Summary



Mode	SafeHold	Sun Acquisition	Inertial	Observing	Delta V	Delta H
Purpose	Acquire the sun in the event of anomalies	Acquire the sun at launch, from SafeHold	Stable pointing, reorientation slews	Perform all-sky scan	Orbit adjust, stationkeeping	Unload momentum
Sensors	CSS, IRU	CSS, IRU	Updated IRU	Updated IRU	Propagated IRU	Propagated IRU
Actuators	RWA	RWA	RWA	RWA	PCS	PCS
Attitude Determination	None	None Init Kalman filter	Kalman Filter	Kalman Filter	propagate q, P	propagate q, P
Control Error	Sun angle error, measured or derived rate	Sun angle error, rate	quaternion, rate	quaternion, rate	quaternion, rate	system momentum integrated rate
Control Law	PD	PD	PD	PD	PD, PWM	PD, PWM

Linear Stability

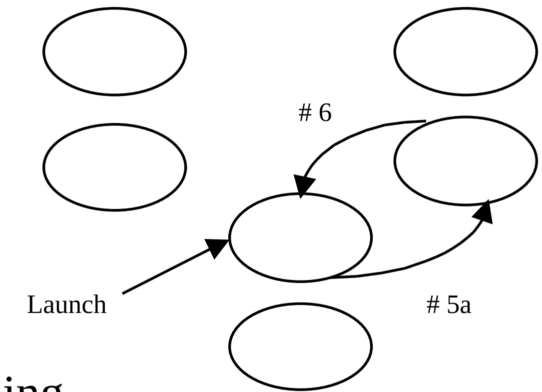


- Rigid body analysis shows sufficient controller margins
  - Current design practice requires 12 dB gain, 30° phase margin
  - Margins range between 14-26 dB gain, 36-74° phase
- Initial flexible mode analysis shows no control-structure interaction (CSI)
  - Separation of 30x between controller bandwidth and first flexible modes provides adequate attenuation
  - ACS software carrying requirement to provide a 4th order elliptic torque filter if there are future CSI concerns
- Final flexible mode analysis to be completed in August with higher fidelity NASTRAN data

Attitude Determination

- Accomplished by propagating IRU rates with attitude and bias updates determined by a Kalman filter
- IRU, AST and DSS timetagged to 1 ms knowledge, with each sensor's data propagated to a common time epoch
- Attitude off propagated IRU only during thruster modes
- Attitude determination performance:
  - 0.6 arcminutes, one sigma, RSS, in Observing Mode
  - <1°/axis propagated IRU error for 2 hours in Delta V Mode
  - Performance meets requirements in both cases

Operations: Launch and Acquisition



1) Spacecraft launches in Sun Acquisition, with RWAs off
2) Delta II performs yo-yo spin-down to ± 2 RPM
3) ELV separation sensed by Housekeeping RSN, which deploys Solar Arrays, ACS remains in Sun Acq mode
4) H/K RSN relays separation switch to ACE, enabling wheel commanding; Sun Acquisition performs rate damping
5) Upon Solar Array deployment (sensed in ACE), ACS S/W computes tip-off momentum

5a) If high, mode switch to Delta H

5b) If low (< 2 sigma), complete sun acquisition

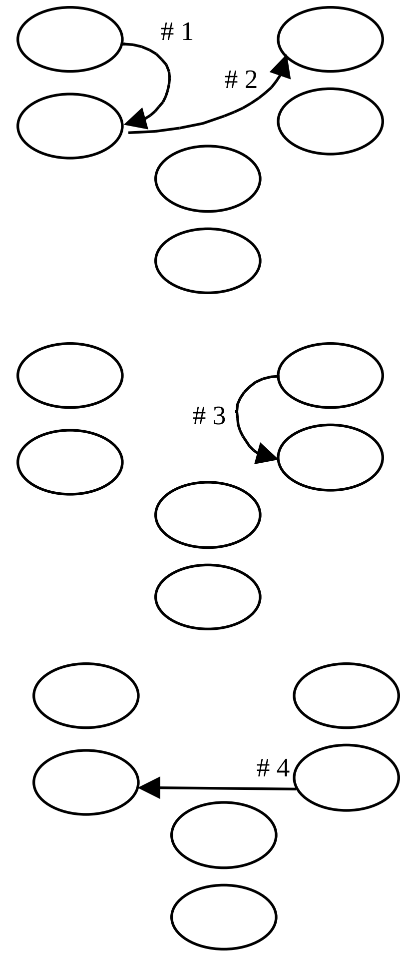
6) After Delta H, mode switch back to Sun Acquisition and acquire

Anomalies

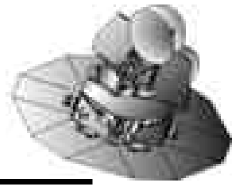
- If entry into SafeHold, SafeHold/IRU controller will acquire within 35 minutes for up to 2 sigma rates

Operations: Delta V

0) Spacecraft receives pre-checked commands to enter Inertial Mode, slew to burn position, and conduct a Delta V of a specified length. Configuration commands (Cat Bed Htr control, etc) and target Q's are uploaded at the same time.
1) At the appointed time, spacecraft enters Inertial Mode, then slews to first target Q.
2) At burn time, spacecraft enters Delta V mode and starts tracking commanded Q's
3) At end of burn, spacecraft autonomously enters Delta H mode to unload excess momentum.
4) When excess momentum is unloaded, spacecraft enters Inertial Mode at previous target Q, unless it has been updated.

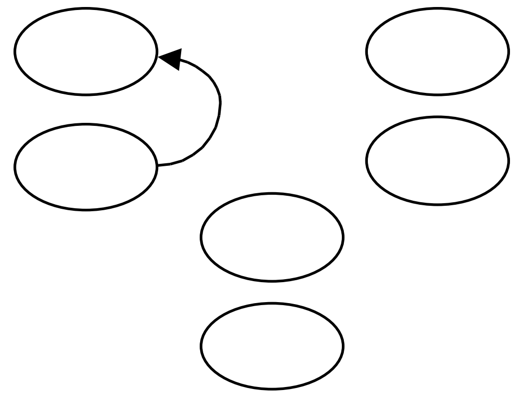


Operations: Inertial/Observing Mode



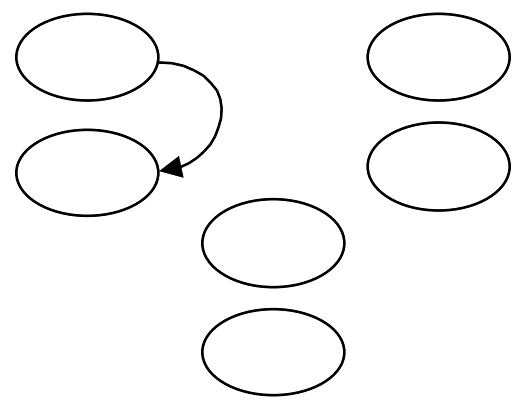
Entering Observing Mode

- Only by ground command from Inertial Mode
- To prevent overshoot, spacecraft should be at offset pointing (22.5 degrees from the sunline) prior to change
- Final survey rate reached through a first order rate command filter, to control ramp-up
- Spacecraft spins up in Observing Mode



Returning to Inertial Mode

- From Observing Mode, only by ground command (can be entered from other modes)
- Spacecraft spins down in Inertial Mode

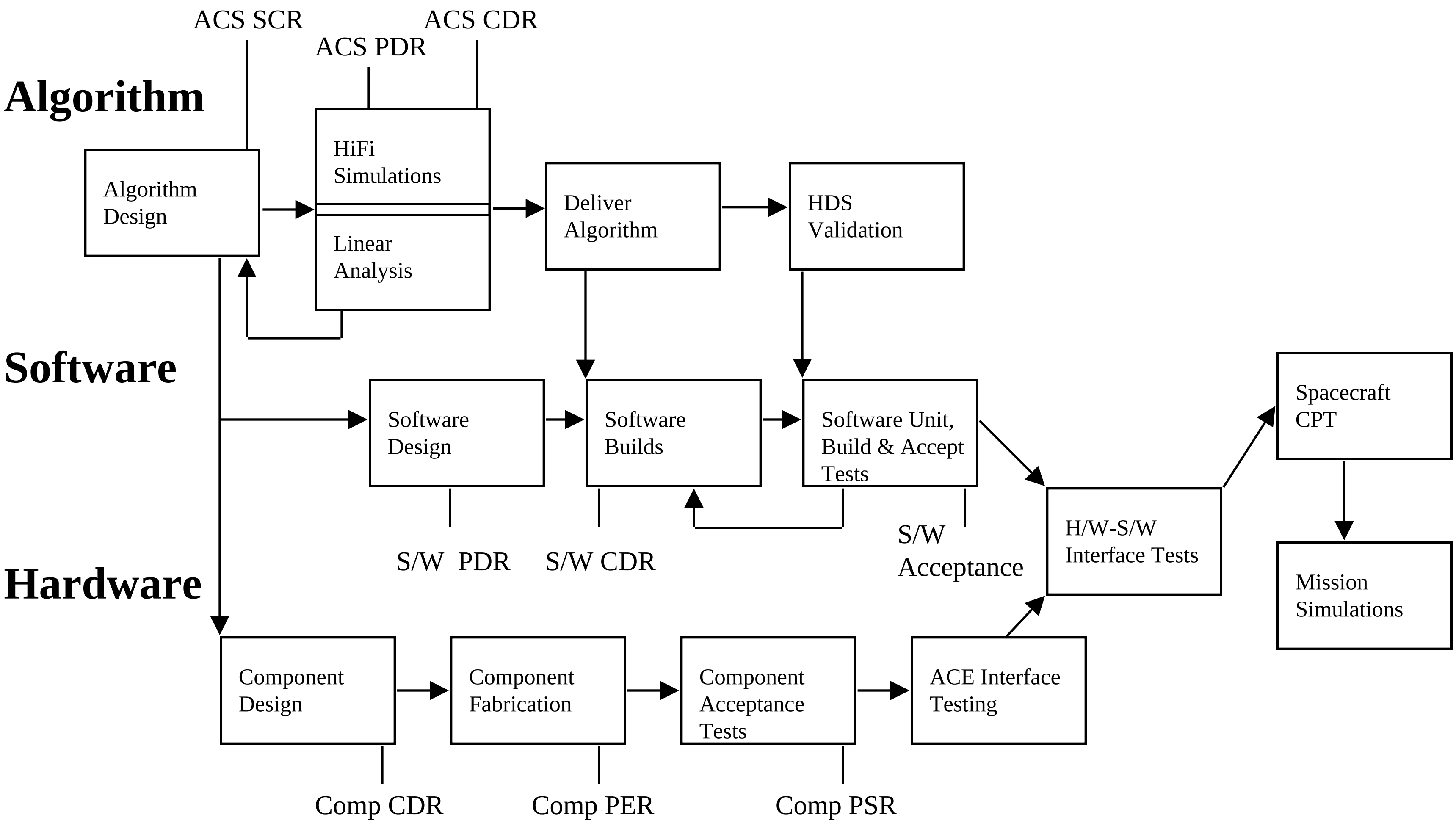


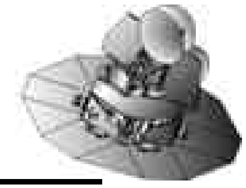
Verification

- Closed loop stability analysis and high fidelity (HiFi) simulations used to design and verify algorithm's performance and robustness
- Hybrid Dynamic Simulator verified against HiFi simulations: used for closed loop software testing
- Component ATP used to verify expected component performance in the presence of environments
- Interface testing during spacecraft I&T verifies hardware, software interfaces and phasing are correct
- Spacecraft performance tests verify end-to-end interfaces, phasing, subsystem functionality
- Mission simulations verify critical ground operations

ACS Development Flow

Attitude Control





Conclusions

- MAP’s ACS requirements are well understood and can be accomplished with the design and implementation presented

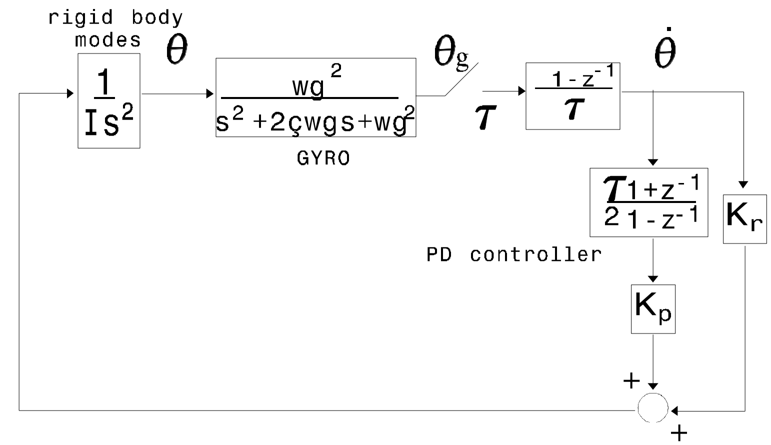
Backup Charts

Component Scroll

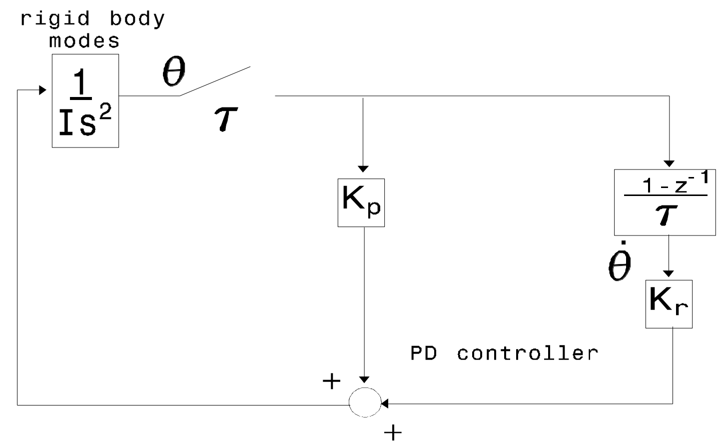
UNIT	Number of Units	Vendor	Mass/ Unit (kg)	Power/ Unit (W)
MAC	1	GSFC	12.8 (MAC)	7.1 (ACE)
AST	1	Lockheed Martin	4.75	12
IRU	2	Kearfott	1.82	7.5
DSS	1	Adcole	1.6	2.0
CSS	6	Adcole	0.02	0.0
RWA	3	Ithaco	14.1	17

- These estimates agree with the MAP mass and power allocations
- AST, DSS and CSS FOV confirmed clear by Mechanical team

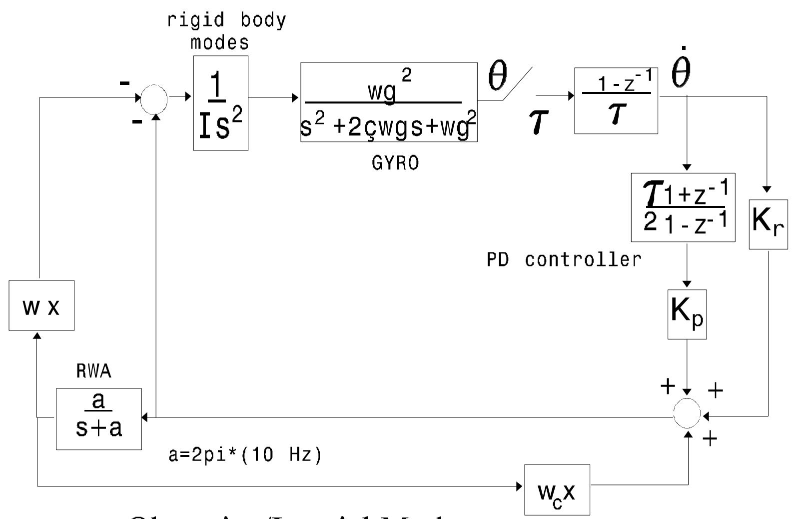
Stability Analysis Models



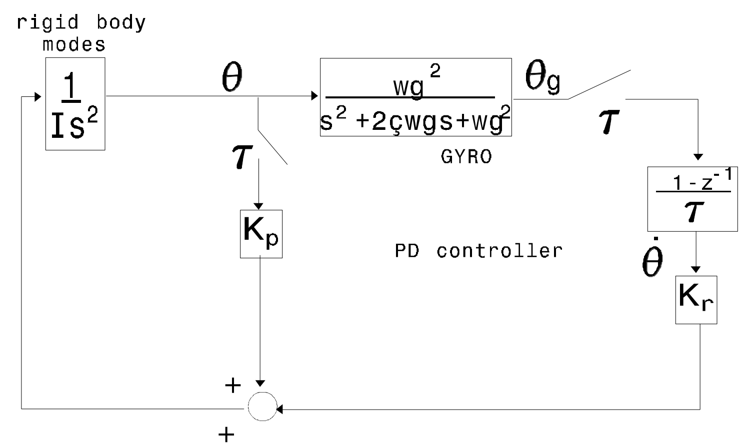
Delta V/Delta H Modes



Safe Hold Mode



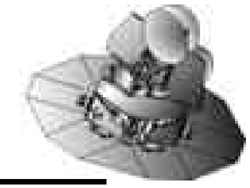
Observing/Inertial Mode



Sun Acquisition Mode

- All modes are Rigid Body only & PD controllers

Linear Stability Results



Attitude Control

- Design Margin Requirements: Gain - 12 dB & Phase - 30 deg
- Margins verified by scaling control gains in nonlinear simulation.

Thruster Mode Controller Gains				Stability Margin 1sec delay			Bandwidth	Linear Range	
AXIS	Ki	Kp	Kr	AXIS	Gain dB	Phase deg	Hz	Degrees	AXIS
X	0.0	5.793	67.99	X	16.2	47.0	0.0218	N/A	X
Y	0.0	5.473	64.242	Y	16.5	47.0	0.0212	N/A	Y
Z	0.0	5.386	63.22	Z	16.9	47.0	0.0244	N/A	Z

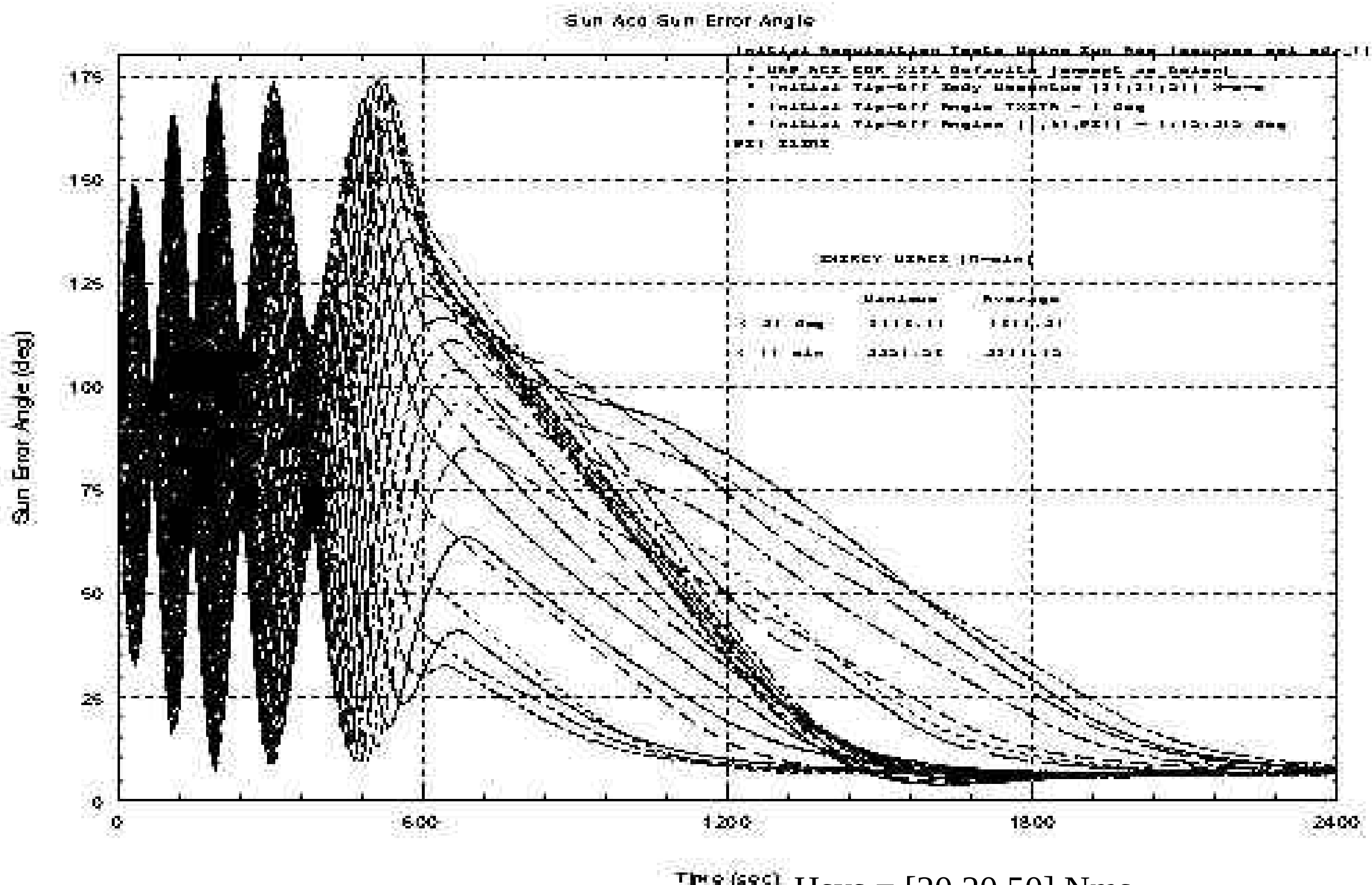
Safehold Mode Controller Gains				Stability Margin 1sec delay			Bandwidth	Linear Range	
AXIS	Ki	Kp	Kr	AXIS	Gain dB	Phase deg	Hz	Degrees	AXIS
X	0.0	0.655	38.582	X	23.5	71.0	0.0109	8.7428	X
Y	0.0	0.478	28.148	Y	26.1	68.0	0.0082	11.9824	Y
Z	0.0	0.414	24.344	Z	25.7	68.0	0.0086	13.8573	Z

Sun Acquisition Controller Gains				Stability Margin 1sec delay			Bandwidth	Linear Range	
AXIS	Ki	Kp	Kr	AXIS	Gain dB	Phase deg	Hz	Degrees	AXIS
X	0.0	0.556	111.987	X	14.3	74.0	0.0306	10.302	X
Y	0.0	0.556	109.819	Y	14.3	74.0	0.0306	10.302	Y
Z	0.0	0.556	90.548	Z	14.3	73.0	0.0306	10.302	Z

Observer/Inertial Controller Gai				Stability Margin 1sec delay			Bandwidth	Linear Range	Stabili
AXIS	Ki	Kp	Kr	AXIS	Gain dB	Phase deg	Hz	Degrees	AXIS
X	0.0	14.607	100.253	X	14.4	37.0	0.0333	0.3923	X
Y	0.0	14.607	97.6	Y	14.4	36.0	0.0333	0.3923	Y
Z	0.0	11.737	81.084	Z	14.4	37.0	0.0333	0.4882	Z

Sun Acquisition Performance

Attitude Control



Hsys = [20,20,50] Nms

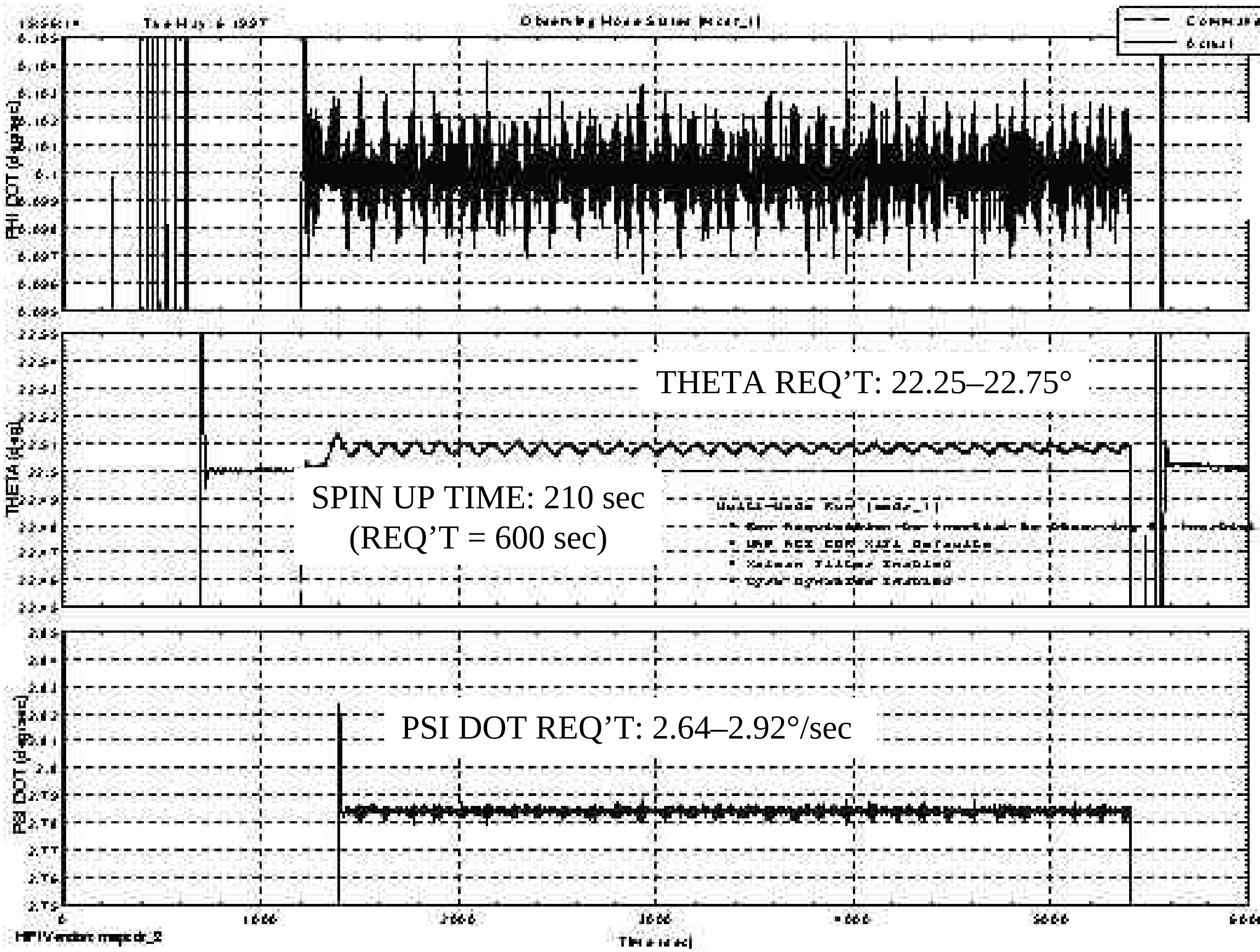
Various Psi angles

Delta V, Phasing Loop

Delta H Mode Performance

Observing Mode Performance

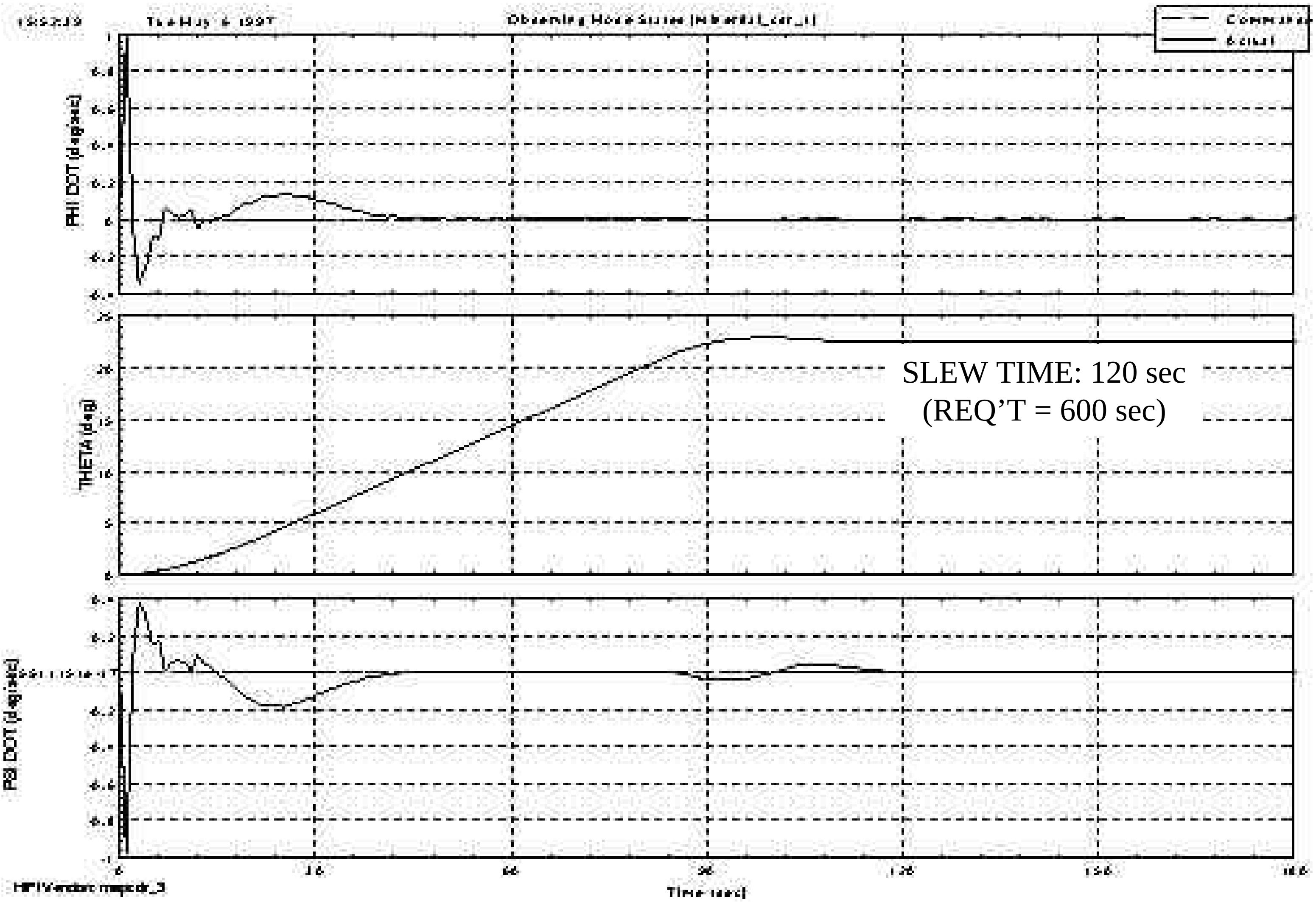
Attitude Control



PHI DOT REQ'T
0.095–0.105°/sec

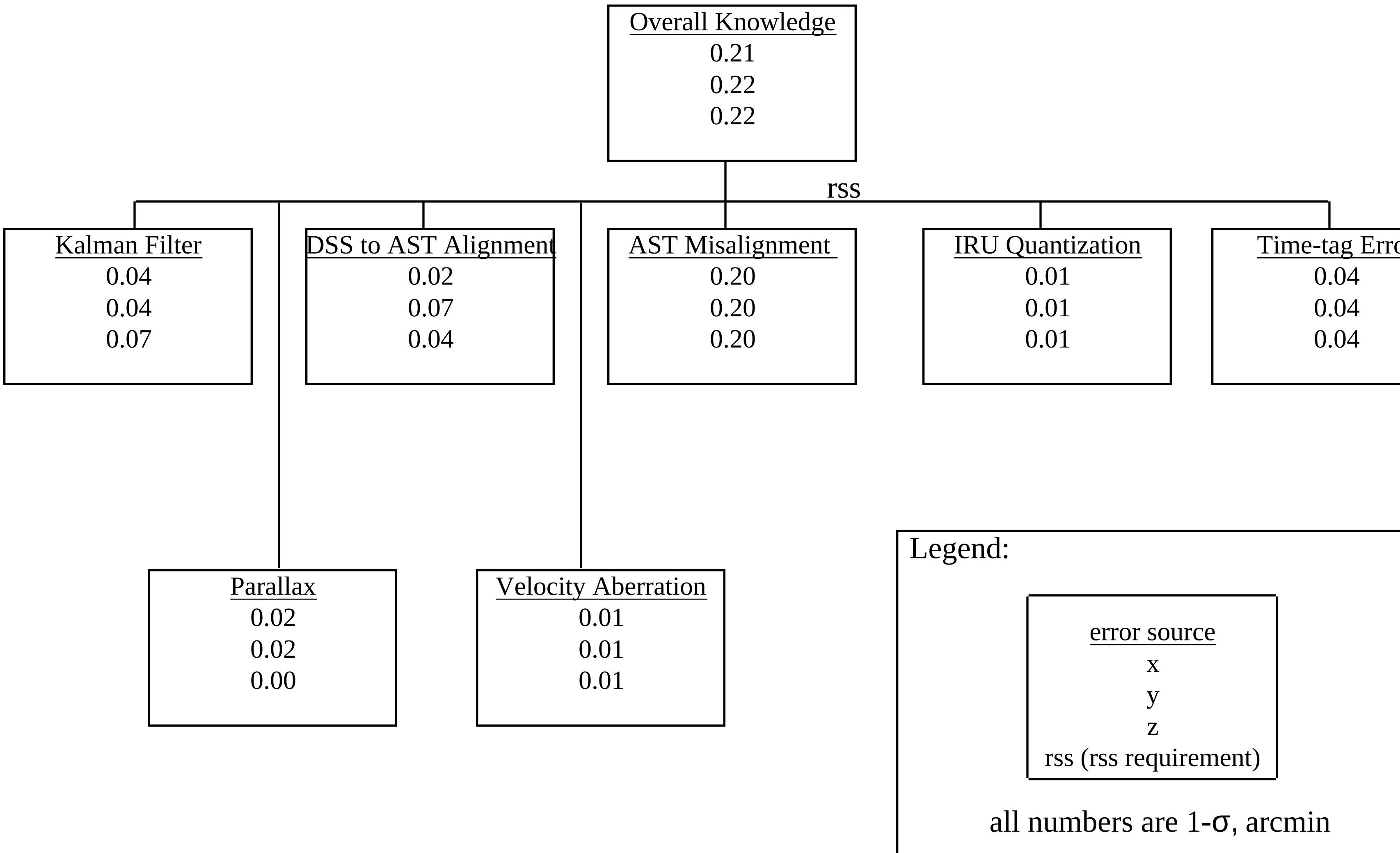
Inertial Mode Slew Performance

Attitude Control



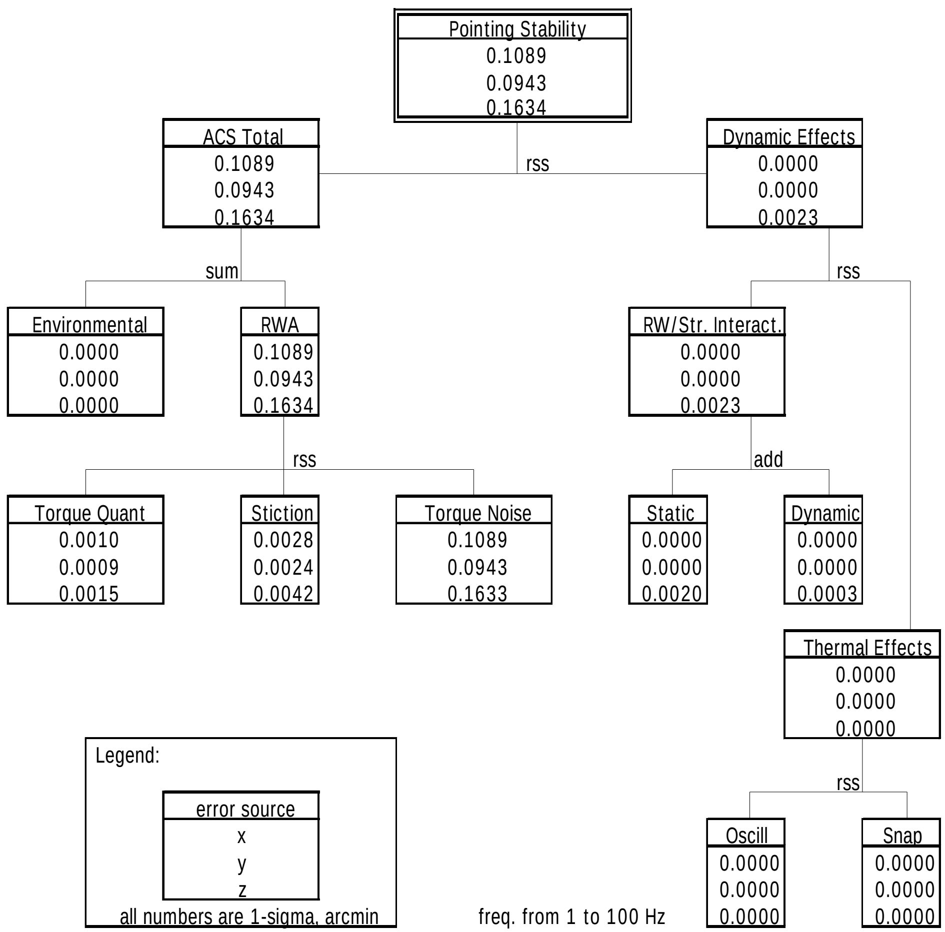
Attitude Knowledge Budget

Attitude Control

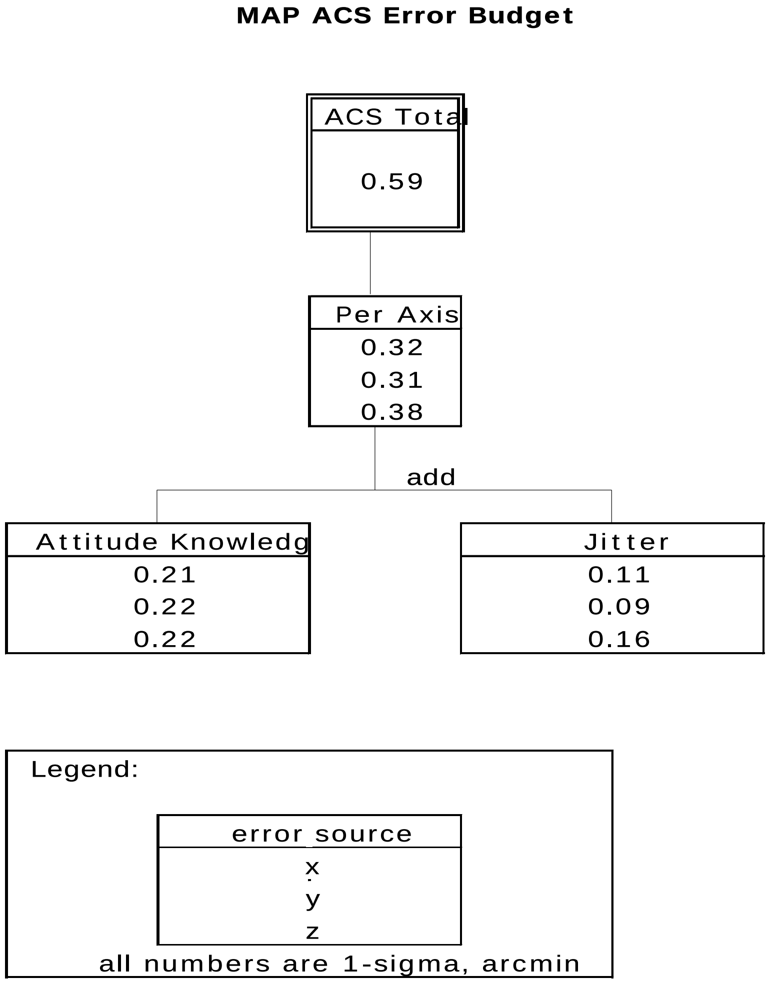


Jitter Budget

MAP ACS
Jitter Budget



ACS Error Budget



MAP
Propulsion
Subsystem

Gary Davis / Code 713

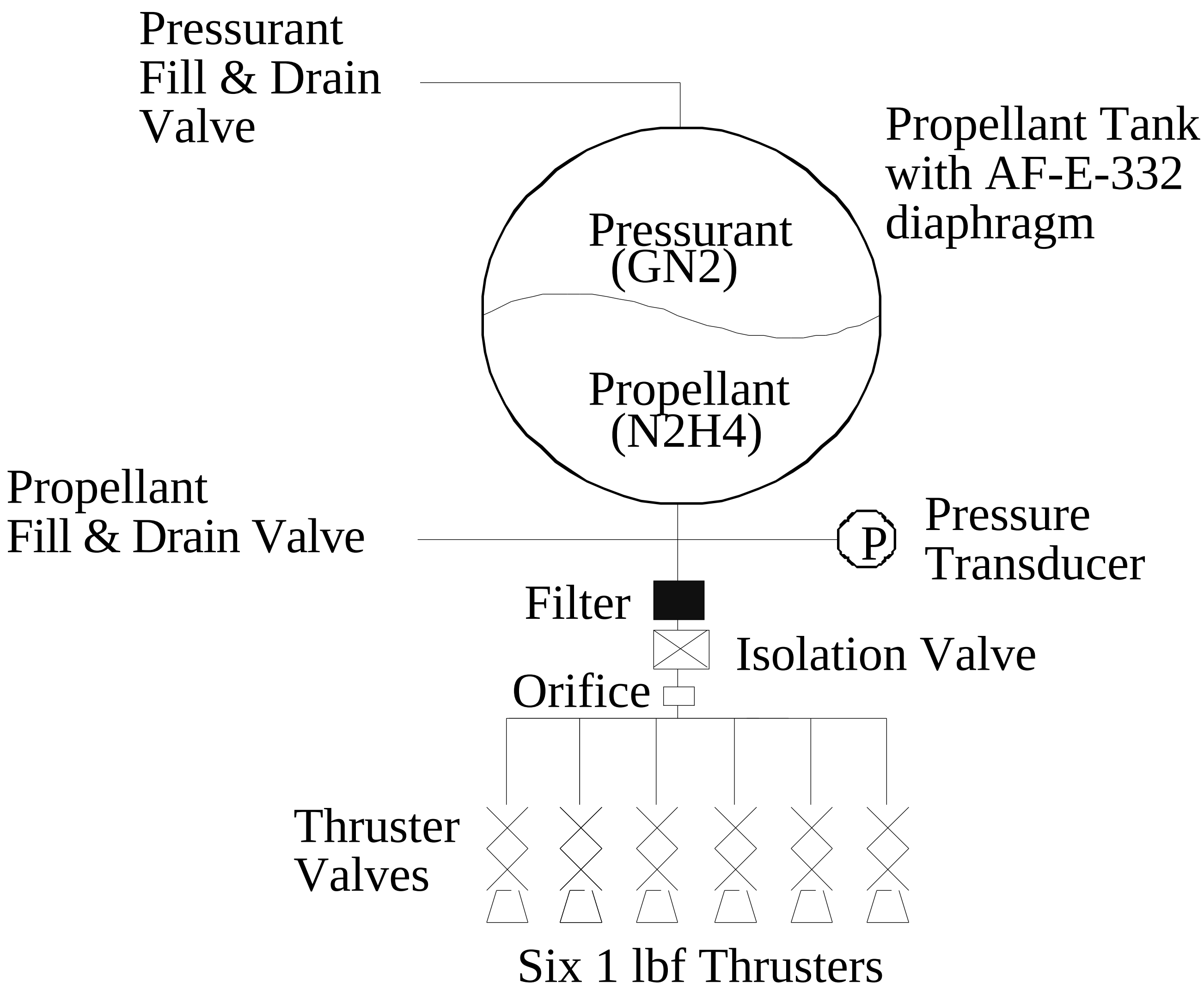
Requirements Overview

- Meet Range Safety Requirements of EWR-127-1
- Null tip-off rates after separation from Delta II
- Perform delta-V maneuvers for trajectory to L2
- Provide control authority during velocity maneuvers
- Perform stationkeeping maneuvers for 2 years at L2
- Perform momentum management for 2 years at L2

Design Overview

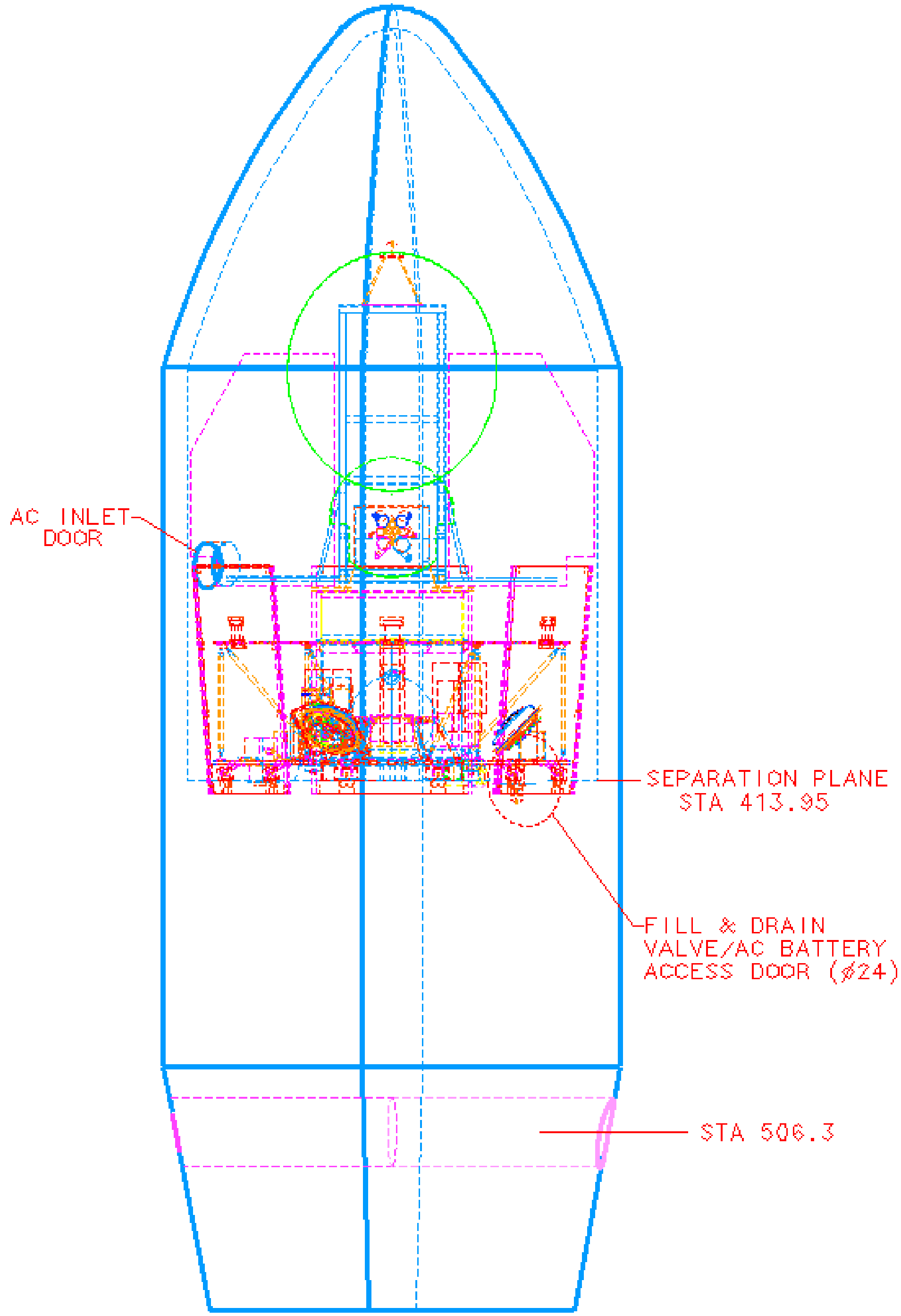
- Unregulated “blowdown” pressurization
  - Maximum operating pressure = 2.41 MPa (350 psia)
- One propellant tank
  - TOMS-EP spare tank built by PSI
  - 72 kg (160 lbm) qualified capacity
- Six 4.45 N (1 lbf) thrusters with dual seat valves
- Latching isolation valve
  - Provides a third mechanical seal during ground operations
  - Valve is only closed during observatory transport to the pad
- Fill and Drain valves located near Delta II fairing door
- Thruster locations
  - Allow velocity changes (_V) in all directions
  - Allow momentum changes (_H) about all three axes

Schematic


Pressurant
Fill & Drain
Valve
Propellant Tank
with AF-E-332
diaphragm
Pressurant
(GN2)
Propellant
(N2H4)
Propellant
Fill & Drain Valve
P
Pressure
Transducer
Filter
Isolation Valve
Orifice
Thruster
Valves
Six 1 lbf Thrusters

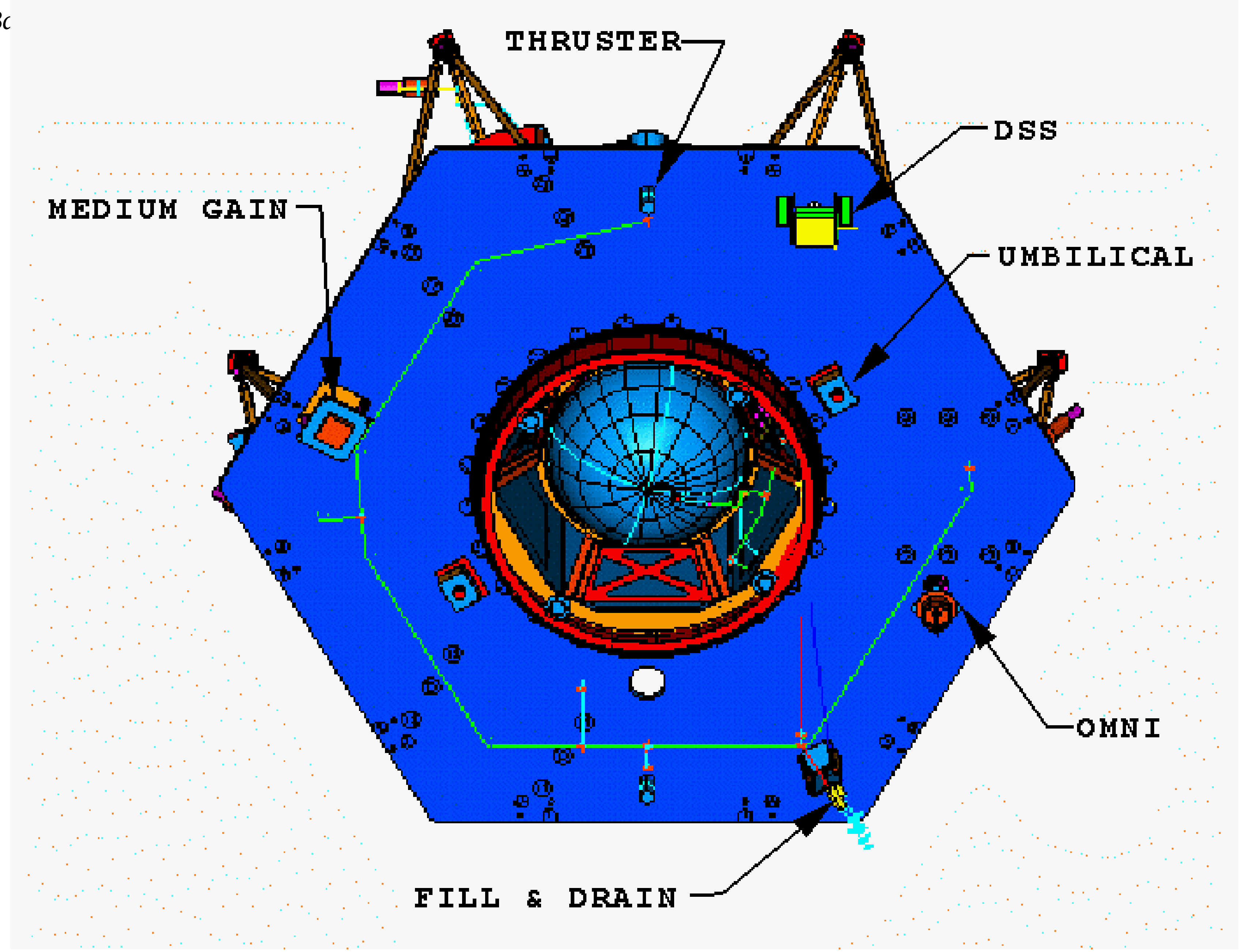
Fill & Drain Valve Access (1 of 2)

Propulsion Subsystem (Backup Charts)



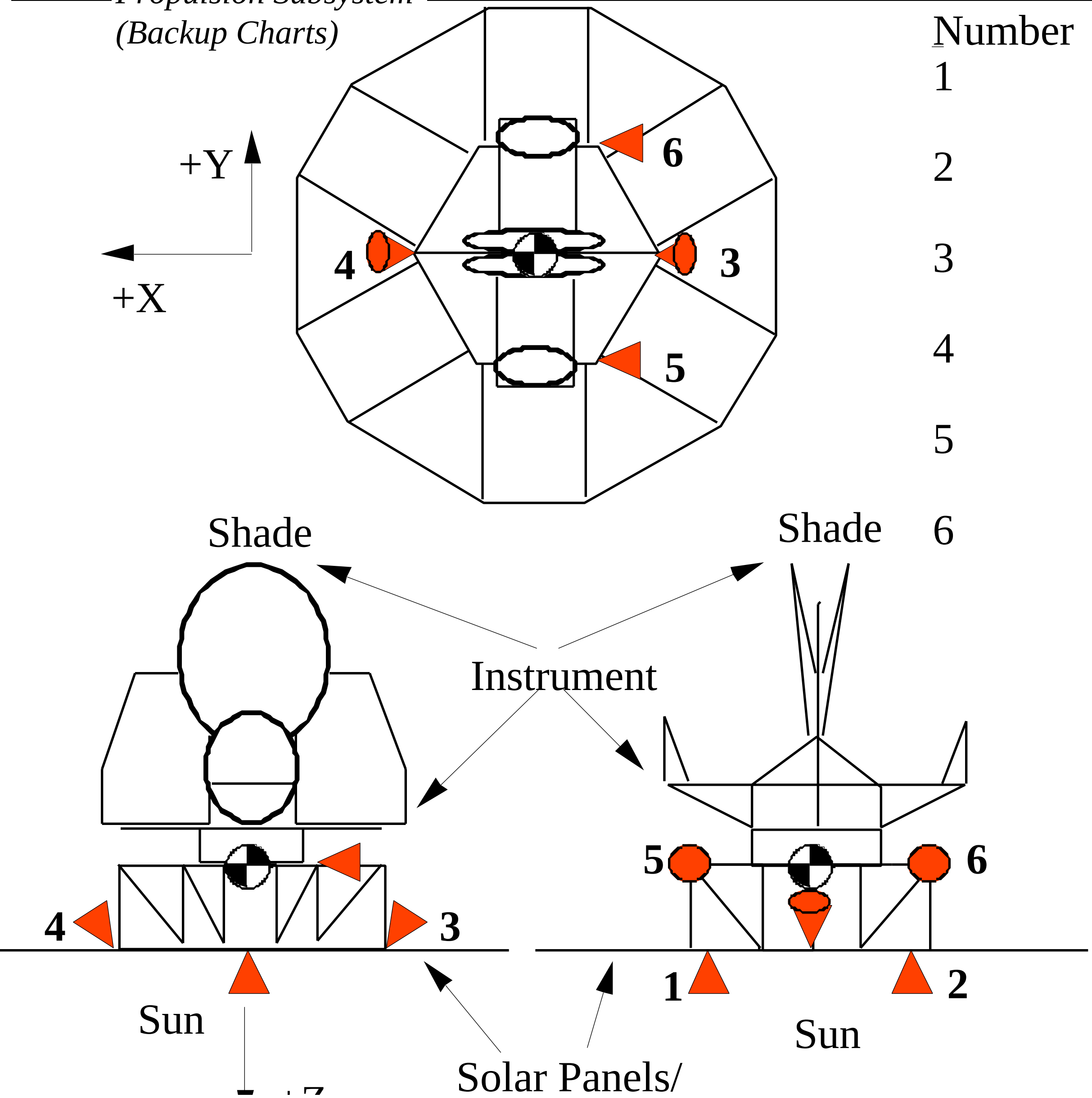
MAP-ACCESS DOOR LOCATION

Fill & Drain Valve Access (2 of 2)



Thruster Locations

Propulsion Subsystem
(Backup Charts)



Number	Torque	?H Function	?V Thrus
1	+X	+Roll	-Z
2	-X	-Roll	-Z
3	+Y	+Pitch	+Z
4	-Y	-Pitch	+Z
5	+Z	+Yaw	+X
6	-Z	-Yaw	+X

(NOT TO SCALE)

I & T Flow Overview

Propulsion Subsystem
(Backup Charts)

I & T Readiness Review → Thermal vac test of tubing mockup

- Thermal vac test of tubing mockup
- Pressure surge test of manifold mockup
- Install thermal hardware on tank
- Mount tank to support structure (Receive structure)
- Install components Weld manifold
- Install Thrusters
- Manifold Proof Pressure Test
- Perform close out welds
- Subsystem Proof Test
- Subsystem Leakage Test
- Install thermal hardware on lines
- Heater circuit checkout
- Install Harness
- Electrical / Functional tests
- Gas flow impedance test
- Ship to KSC
- Subsystem leak / electrical / functional / gas flow impedance tests
- Load propellant / pressurize
- Spin Balance
- Close Isolation Valve
- Transport to pad
- Open isolation valve
- Monitor telemetry
- Launch

Summary

- The propulsion subsystem design meets all of the MAP propulsion requirements
- The longest lead item (propellant tank) has been delivered
- All other procurements show schedule margin
- I&T will implement lessons learned from in-house TRMM Reaction Control Subsystem build by Code 713

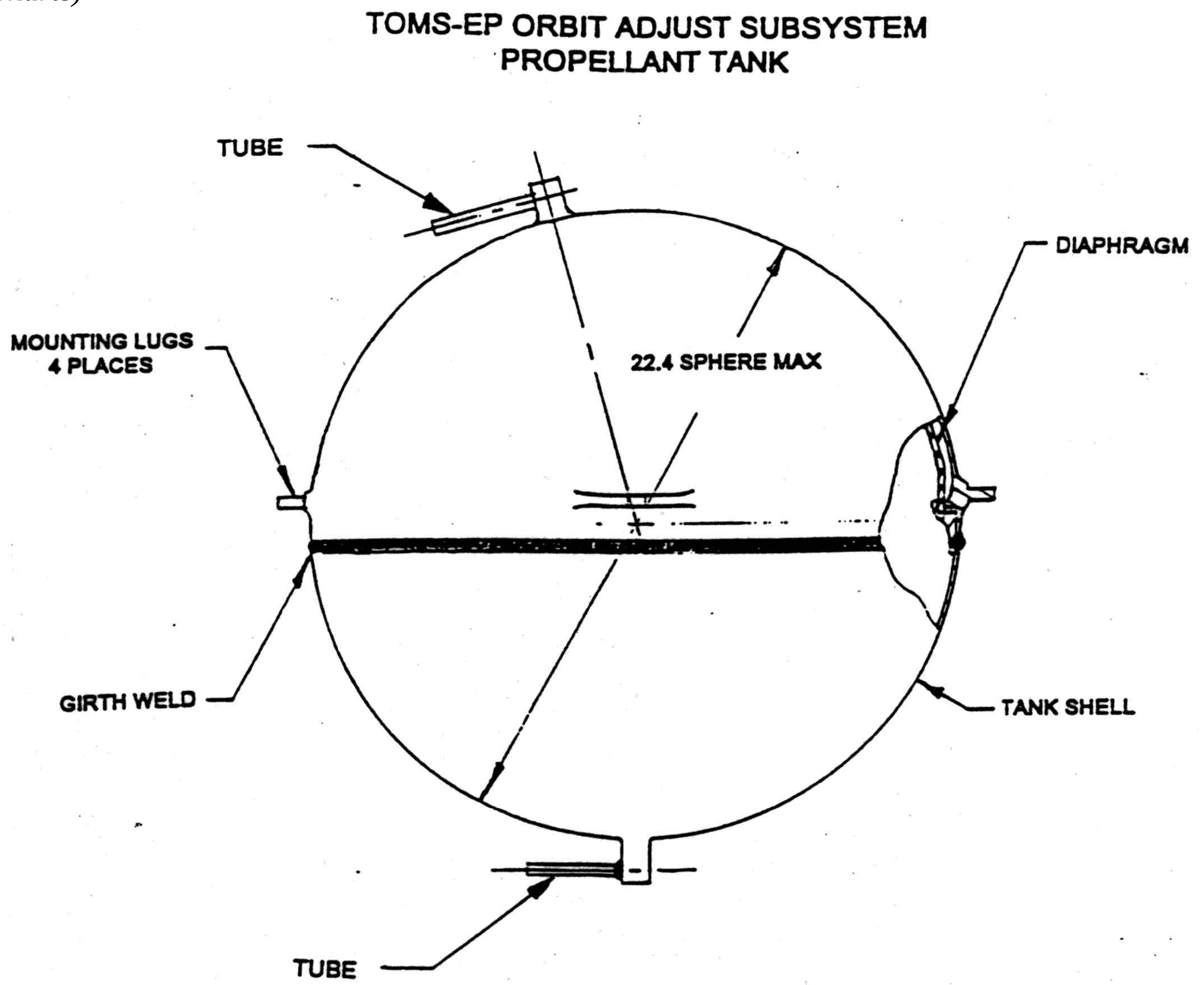
Propellant Tank (1 of 2)

- TOMS-EP spare tank donated to MAP by the TOMS project
- Positive expulsion, elastomeric diaphragm propellant tank
- Designed and built by PSI of Los Angeles CA
- Fracture analysis has been approved by 45’th Space Wing

QuickTime™ and a
Photo - JPEG decompressor
are needed to see this picture.

- Qualified by similarity to FLTSATCOM in 1992
- Flight heritage on over 90 similar tanks
  – FLTSATCOM, EXOSAT, IUS, CENTAUR, HEAO, DSCS, TOMS-EP, and classified programs

Propellant Tank (2 of 2)



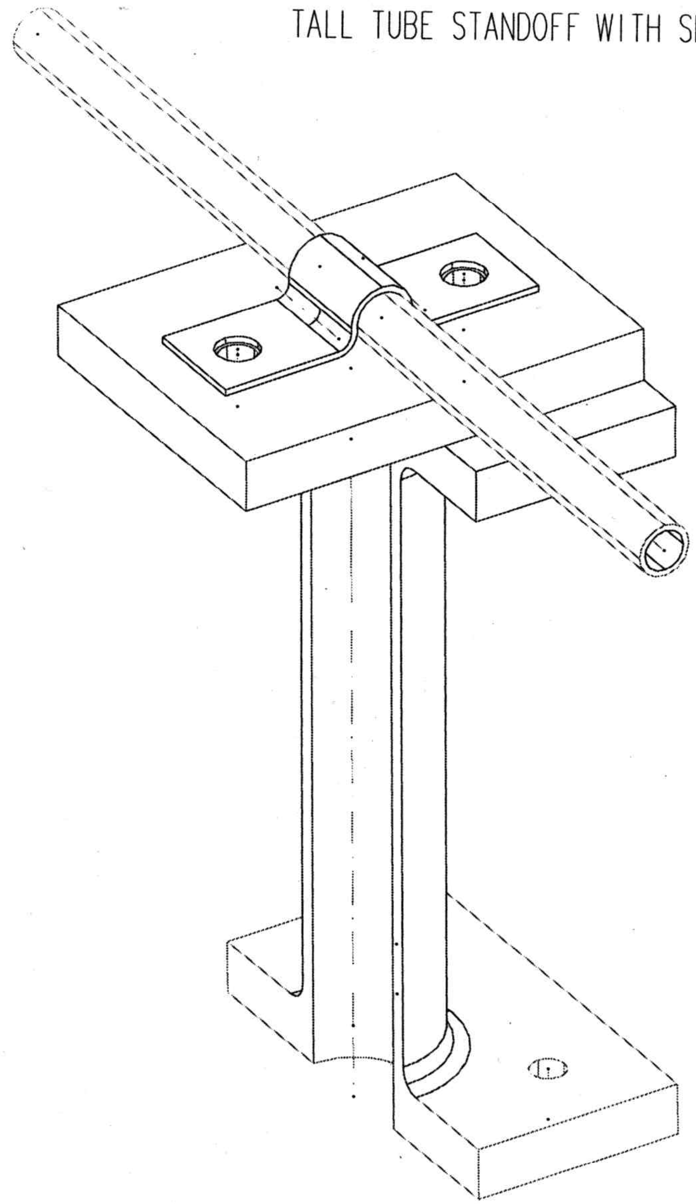
MAP

Thrusters

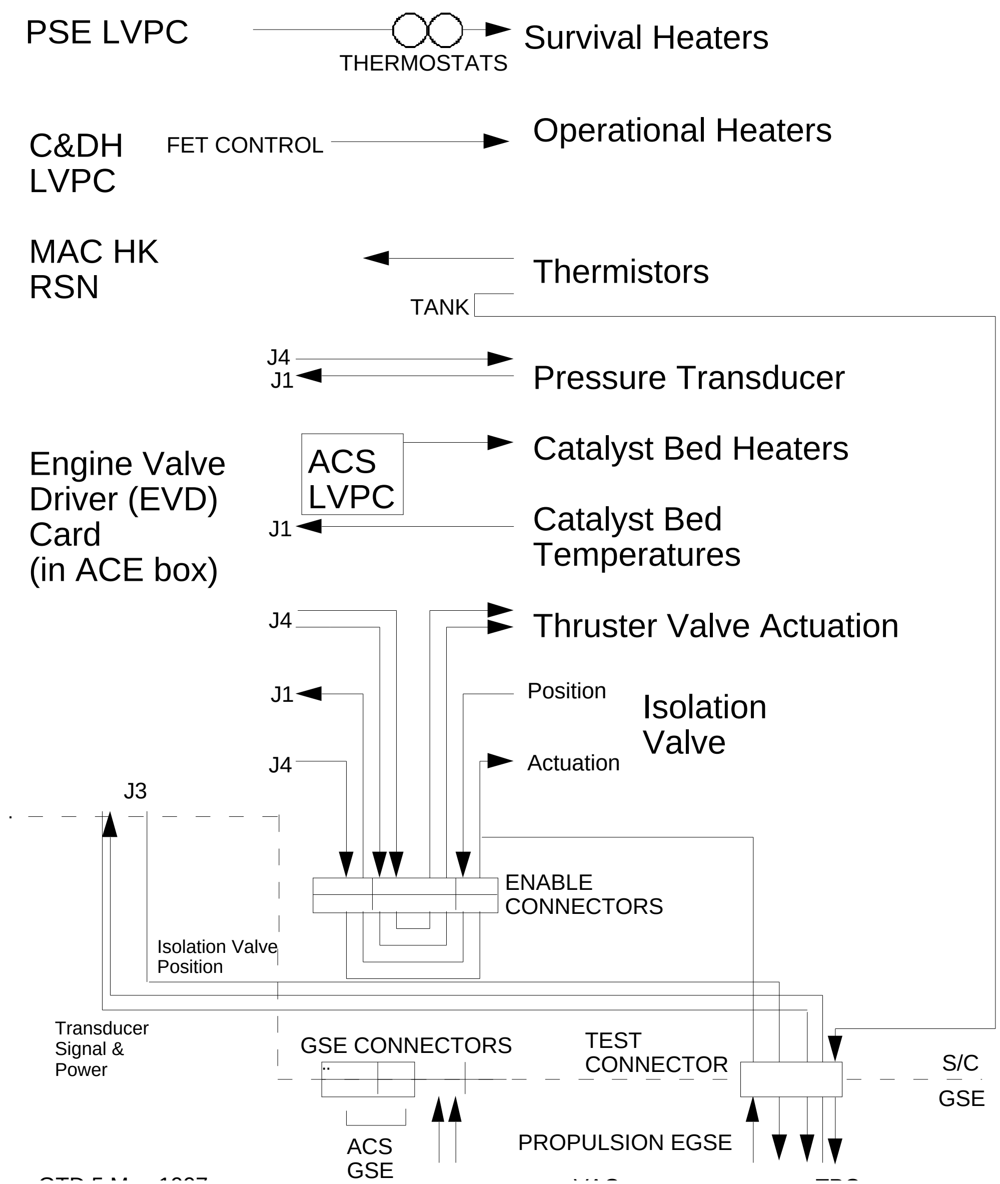
- Thruster attributes from specification
  - Thrust level: 4.45 to 1 N (1 to 0.24 lbf) over 350 to 80 psia inlet pressure
  - Duty cycle: unlimited with 0.040 sec on-time
  - Proof pressure: 720 psig
  - Burst pressure: 960 psig
  - Solenoid coil resistance: 175 _ or greater
  - Conductive heat flow: 5 W max
  - Propellant throughput: 35 kg
  - Number of pulses: 50000
  - Thermal equipment: redundant valve heaters, catalyst bed heater, PRT for catalyst bed temperature, thermistor for valve temperature
- Major thruster acceptance tests from SOW
  - Electrical functional
  - Internal leakage
  - Random vibration
  - Performance firing
  - Proof pressure
  - Gas flow impedance

Tubing Standoff Design

- Machined from ULTEM 1000
- Incorporates shims to meet tubes precisely
- Designed for low thermal conduction from tube
- Designed for 25 pound handling load (with 4X margin)



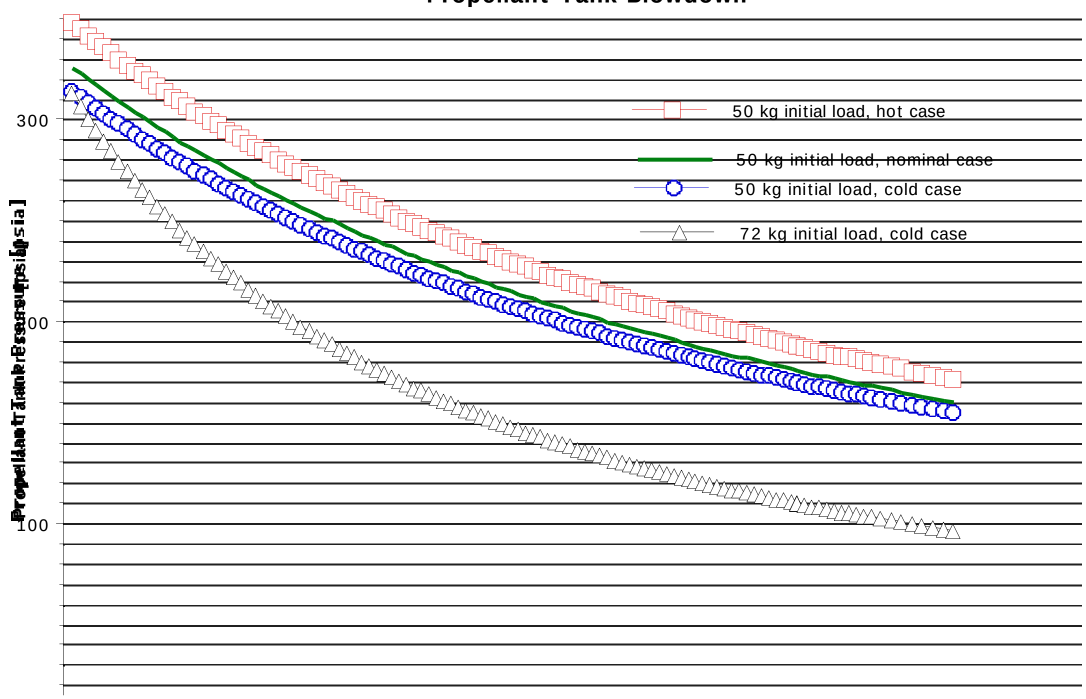
Interface Block Diagram



Blowdown Tank Pressure

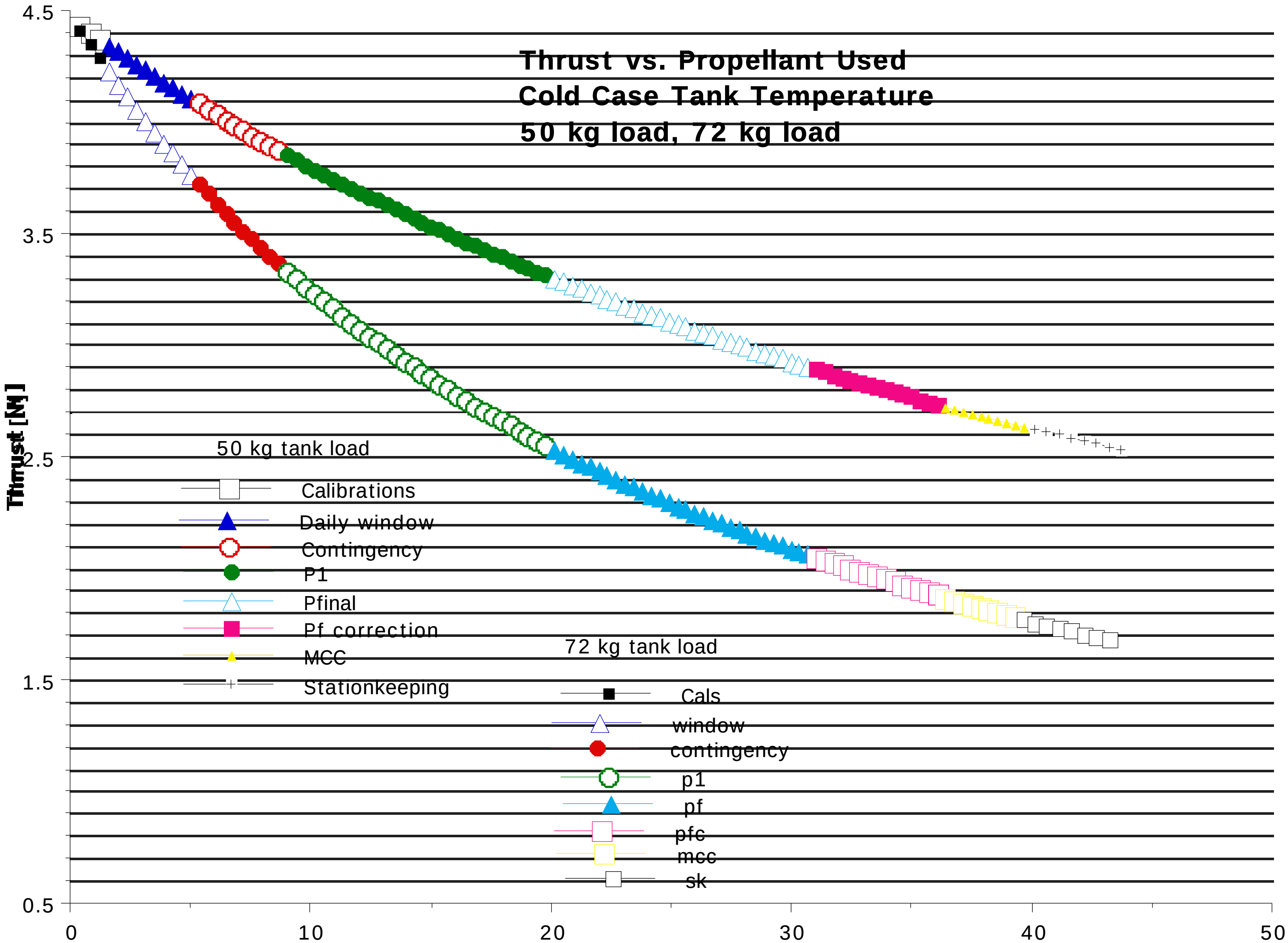
- Nominal tank temperature in flight = 20 °C
  - Worst case hot tank temperature = 40 °C (313 K)
  - Worst case cold tank temperature = 10 °C (283 K)
- Tank MEOP is 350 psia
  - Tank is loaded at 20 °C (293 K)
  - Flight tank pressure on the ground = 327.6 psia = 312.9 psig

Propellant Tank Blowdown



Thrust vs. Propellant Used

Propulsion Subsystem
(Backup Charts)

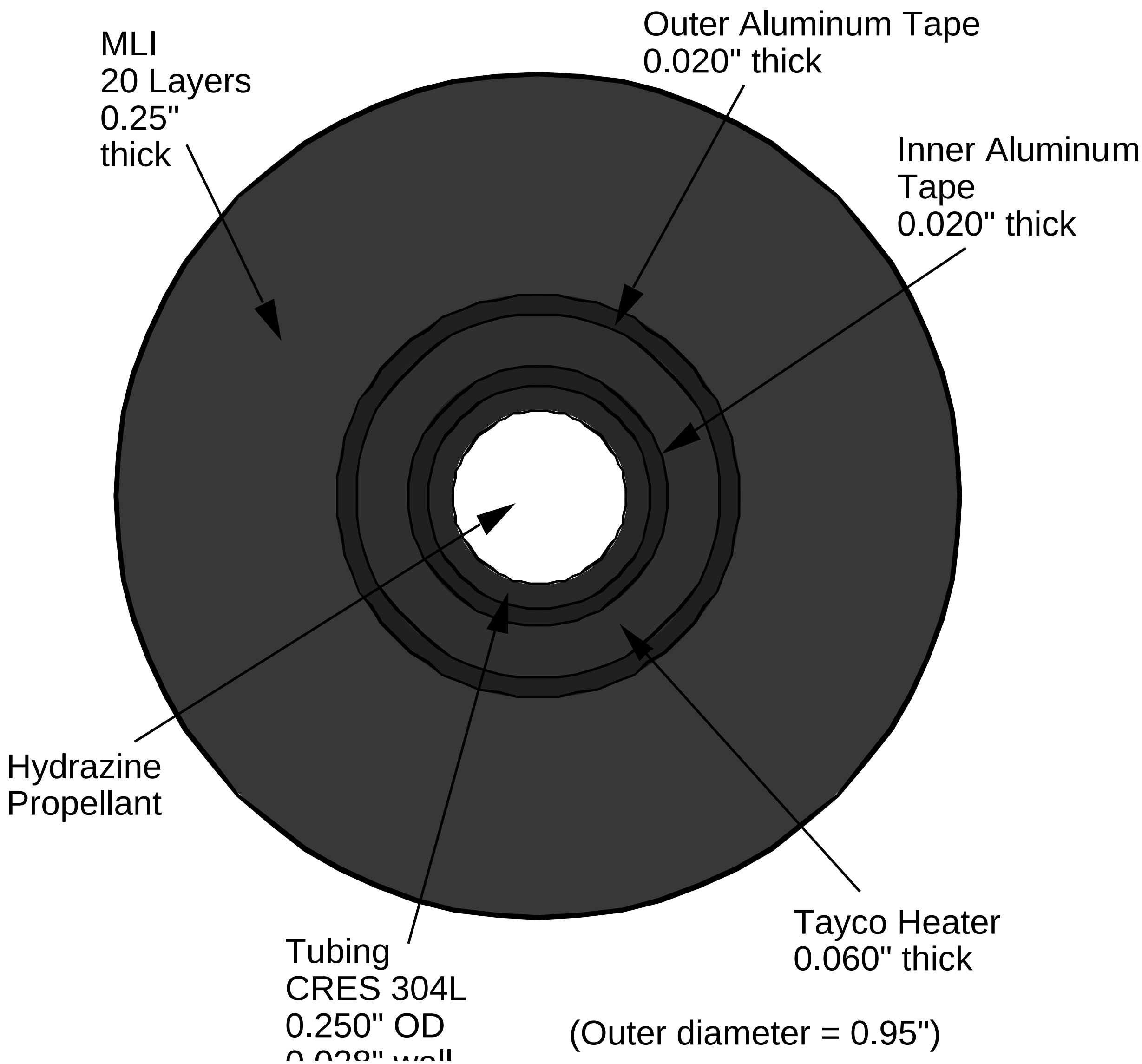


Assumptions Used in Propellant Budget

- S/C mass = 708 kg
- Steady-state Isp = 220 s
- ACS propellant = 10 % of _V propellant
- Thruster mismatch propellant = 5 % of _V propellant
- Expulsion + line residuals = 1 kg
- Momentum management propellant = 1 kg
- Initial tank load = 50 kg
- Initial tank pressure = 316 psia (cold case)
  - Uses ideal gas equation
  - Ignores diaphragm volume
  - Ignores contraction of tank due to pressure and temperature changes
- S/C is oriented so radial thrusters' force lies along the desired velocity vector (except for L2 stationkeeping)
  - A _V error of 5 % is assumed in order to determine correction needed
- Budget will be updated and tracked every 6 months

Tubing Thermal Design

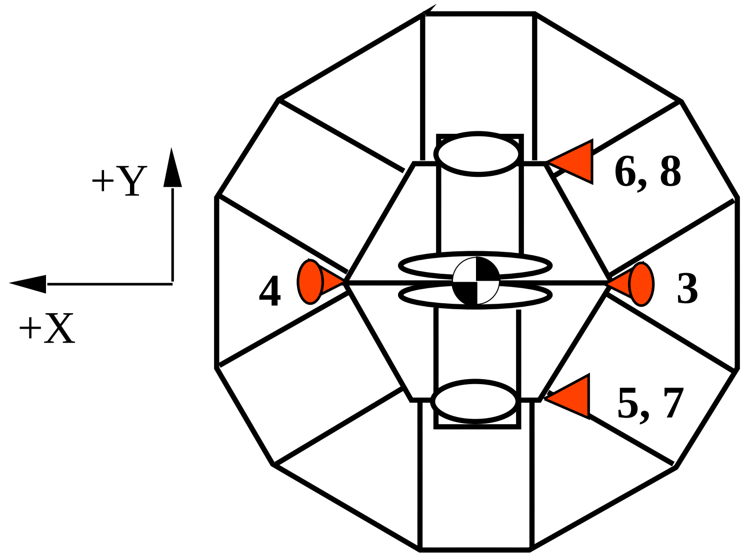
Propulsion Subsystem
(Backup Charts)

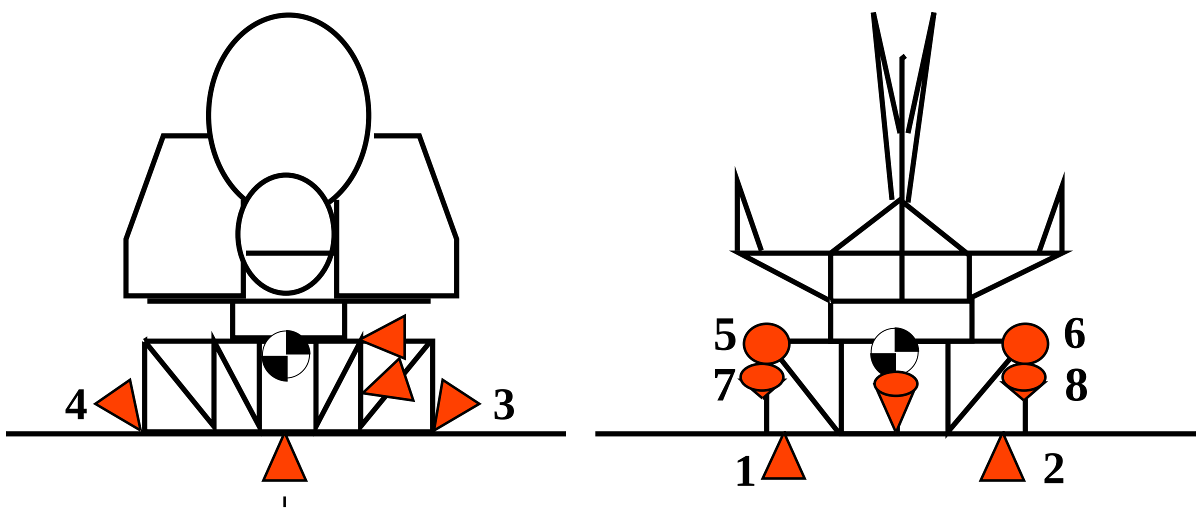


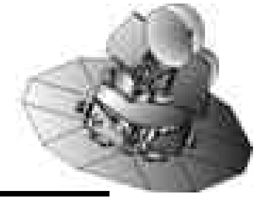
Propulsion Layout

Propulsion Subsystem (Backup Charts)

- 8 Thrusters (was 6) add control capability in the event of any 1 failed thruster





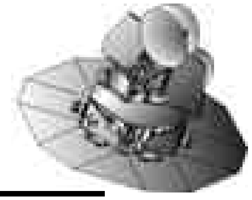


MAP Flight Software

Product Team Lead - Bruce Savadkin

ACS S/W Lead - Mark Walters
C&DH S/W Lead - Jane Marquart
S/W Testing Lead - Maureen Bartholomew

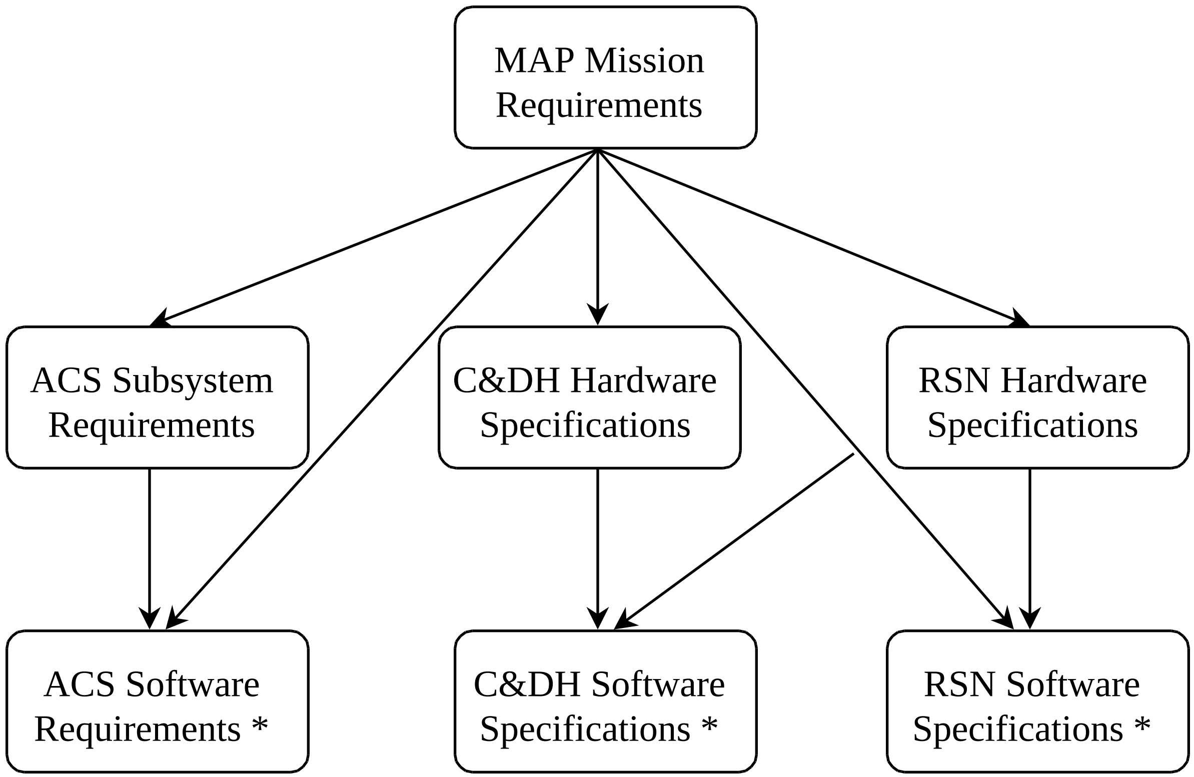
Agenda



- Requirements
- Flight Software Overview
- Software Development Approach
- Reviews
- Documentation
- Configuration Management
- Verification Approach
- Flight Software Maintenance
- Processor Resource Estimates
- Conclusions

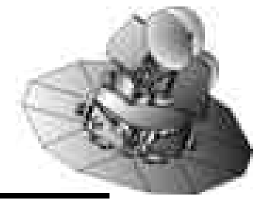
Requirements Flowdown

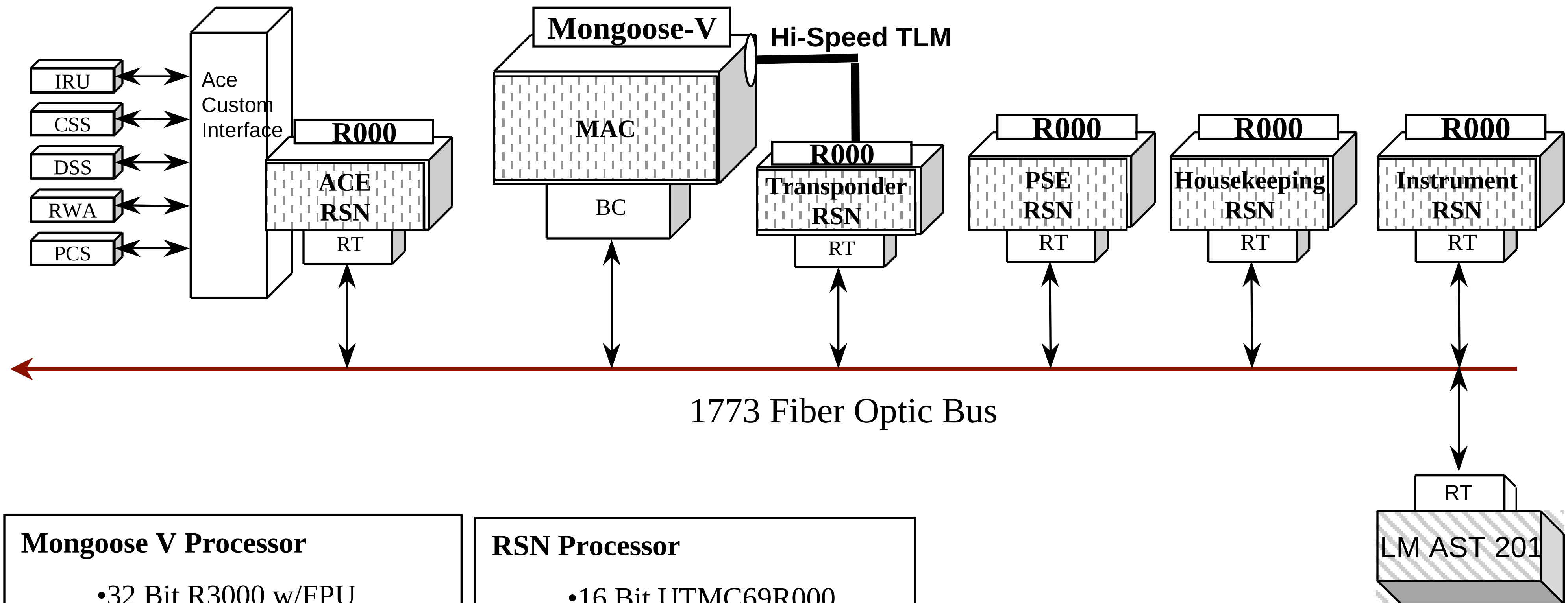
Flight Software



* Derived Requirements focus on
- •Operational Convenience
- •On-orbit Maintenance

Flight Software Context





Mongoose V Processor

- •32 Bit R3000 w/FPU
- •12.5 Mhz
- •4 MB EEPROM
- •32 MB DRAM (processor)
- •256 MB DRAM (recorder)

RSN Processor

- •16 Bit UTMC69R000
- •12 Mhz
- •128k EEPROM
- •32k RAM* (2 buses)

* ACE RSN Contains 128k of Instruction RAM

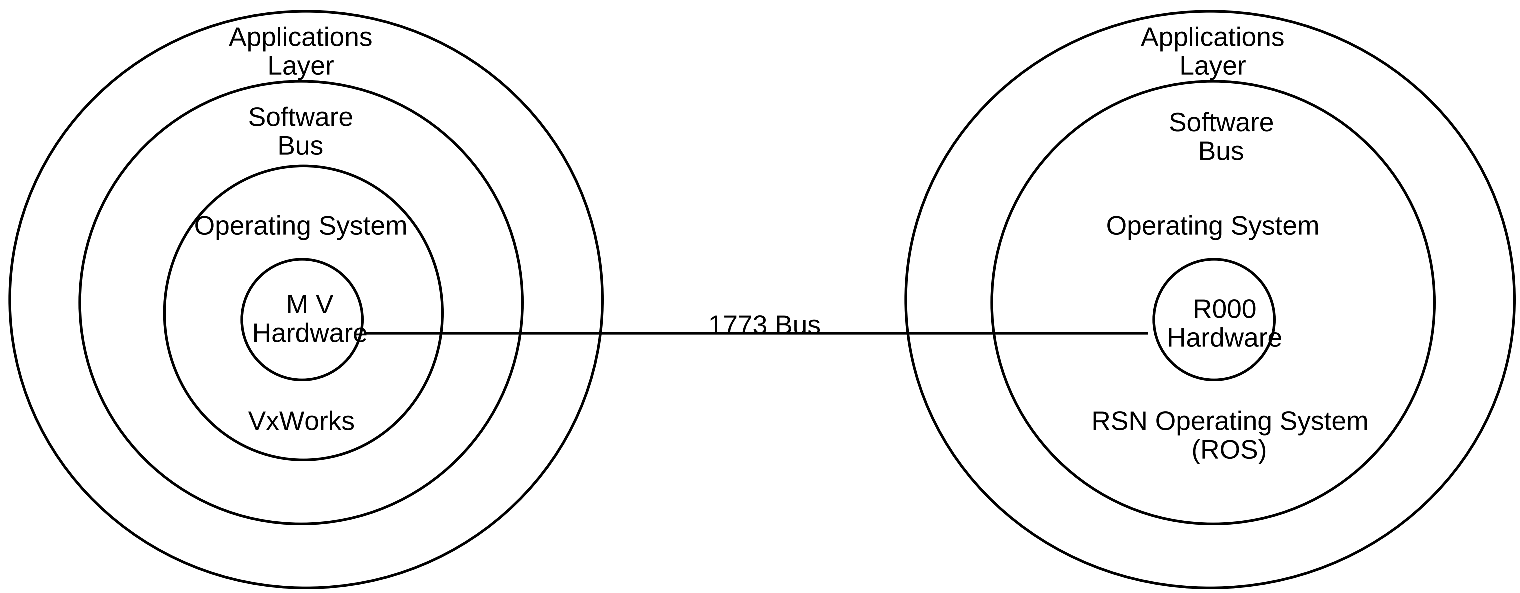
GSFC Developed Flight Software

Vendor Developed Flight Software

Layered Approach

Mongoose Architecture

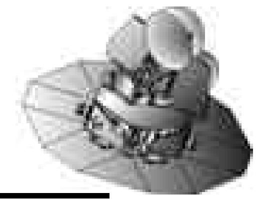
RSN Architecture



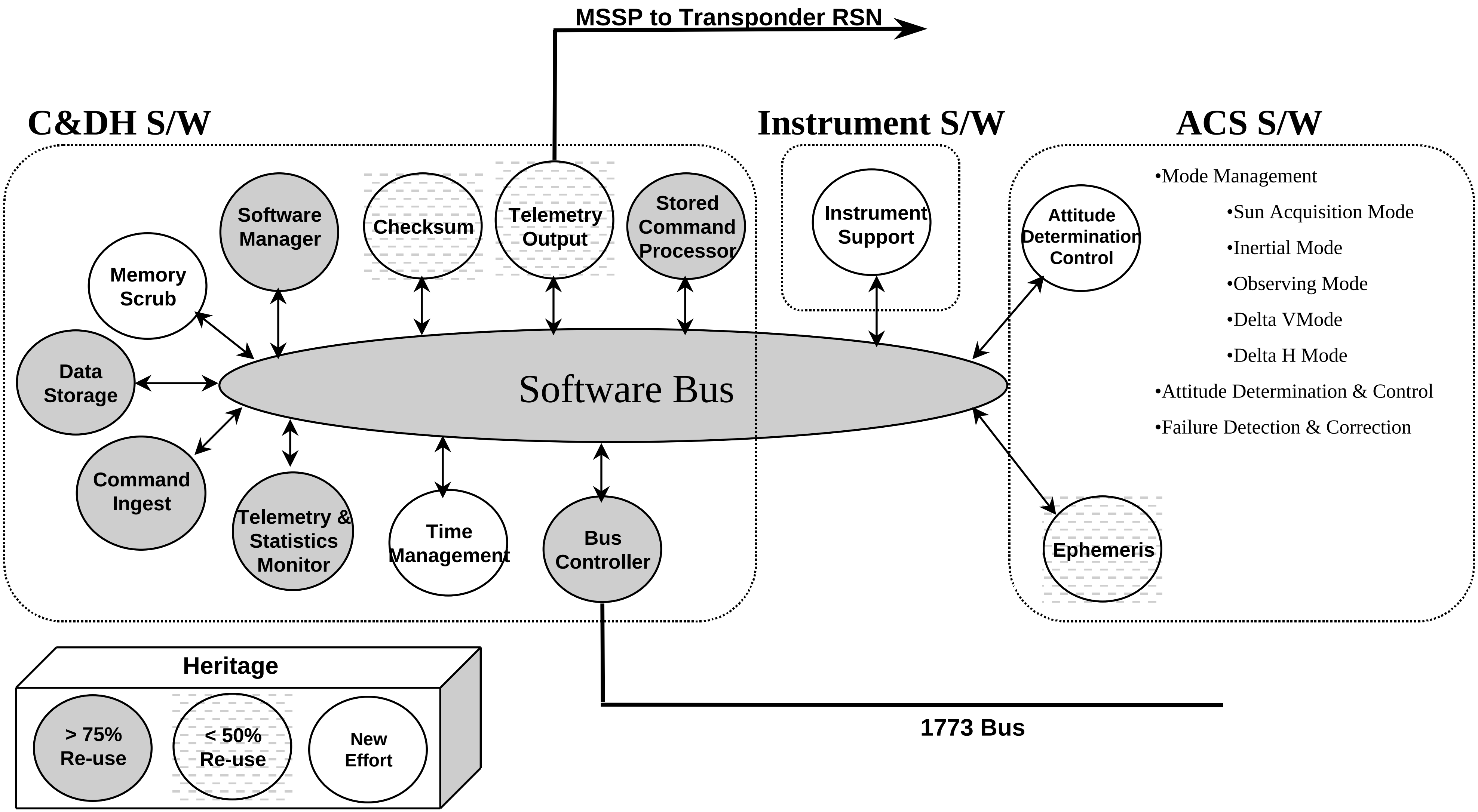
•Wind River's VxWorks Operating System Provides:
- •Source level debugging at the task level
- •Performance Monitoring
- •Board support package (R3000)

•GSFC's RSN OS provides:
- • Priority based multi-tasking
- •Memory management
- •Queuing
- •1773 Remote Terminal
- •Communications Layer (Software Bus)

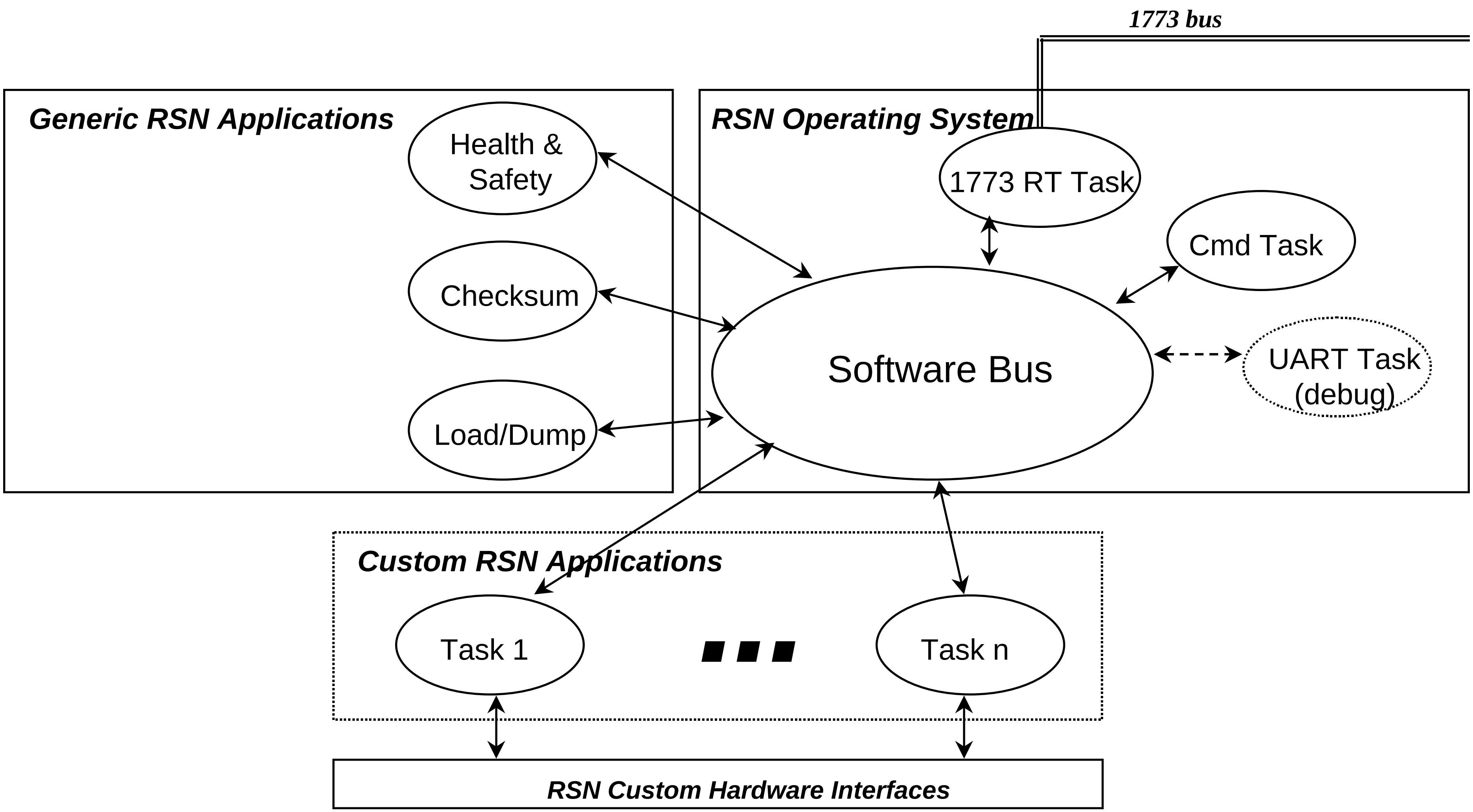
Mongoose Software Environment



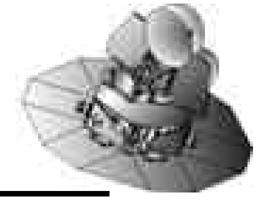
Flight Software



RSN Software Environment



Custom RSN Applications

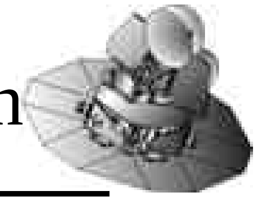


- ACE RSN
  - Sensor Data Acquisition
  - Actuator Commanding
  - Independent Safehold
  - Power Switching
- Transponder RSN
  - Uplink codeblock construction
  - Low-rate downlink management
  - Transponder command & telemetry interface
- PSE RSN
  - Calculates Battery State-of-Charge
  - Controls Battery Current
  - Monitors Power System Health
  - Power Switching
- Housekeeping RSN
  - Spacecraft thermister monitoring
  - Launch & Separation services
  - Power Switching
- Instrument RSN (DEU)
  - Science data processing
  - Science housekeeping data processing
  - Instrument command & telemetry interface

Management Approach

- Project Level
  - Detailed Flight Software development and test schedule is integrated with component and system level activities
  - Monthly MAP Schedule and Resource analysis meetings
  - Monthly MAP Project Flight Software Status Meetings
- Subsystem Level
  - Weekly Flight Software design meetings
  - Several regular status meetings covering the following topics:
    - ACS Software
    - C&DH/RSN Software
    - Testing
  - More detailed lab schedules are utilized to manage the day-to-day activities of the flight software team

C&DH S/W Development Approach



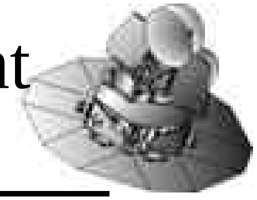
Flight Software

- **C&DH Build 1 Contains:**
  - OS & Software Bus
  - Cmd & Tlm
  - 1773 Bus Controller
  - Health & Safety
  - Load/Dump & Time
  - Transponder RSN S/W
  - PSE RSN S/W
- **Supports:**
  - Build Testing
  - ETU H/W Testing
  - ACS/ACE Build 1

- **C&DH Build 2 Contains:**
  - Processor Modes
  - Recorder
  - Stored Commands
  - Telemetry Monitoring
- **Supports:**
  - Build Testing
  - Flight H/W Testing

- **C&DH Build 3 Contains:**
  - MAP Tlm Monitoring
  - MAP Stored Commands
  - Housekeeping RSN
  - Instrument Support
  - DEU RSN S/W
- **Supports:**
  - Build Testing
  - Acceptance Testing
  - Spacecraft I&T

Mongoose ACS S/W Development Approach



- **ACS Build 1 Contains:**
  - Cmd & Tlm I/F’s
  - Raw Sensor Data Processing
  - Actuator Commanding
  - ACS Mode Mgmt.
  - Solar Ephemeris
- **Supports:**
  - ACS End-to-end testing
  - Build testing

- **ACS Build 2 Contains:**
  - Attitude Determination
  - S/C Ephemeris
  - Failure Detection & Correction
- **Supports:**
  - Build Testing
  - Acceptance Testing
  - Spacecraft I&T

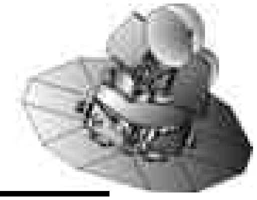
ACE RSN S/W Development Approach

- **ACE Build 1 Contains:**
  - Cmd & Tlm I/F's
  - Data Acquisition
  - Actuator Commanding
- **Supports:**
  - ACS End-to-end testing
  - ACE ETU Testing
  - Build Testing

- **ACE Build 2 Contains:**
  - H/W Monitoring
  - Safehold
- **Supports**
  - Build Testing
  - Acceptance Testing
  - Spacecraft I&T

Review Philosophy

- Internal Review Process
  - Requirements Review
  - Design Review
  - Code Inspection Review
  - Concentrating our review process on software without heritage
  - Reviews attended by: Software team members, Systems, and Subsystem leads
  - Software with heritage undergoes delta reviews
  - Action items are tracked to closure
  - Many reviews have already occurred
- External Review Process
  - ACS Software PDR (4/97)
  - Combined (ACS, C&DH, RSN) Flight Software CDR (9/97)
  - Non-MAP reviewers included



Documentation

- Flight Software Development Plan
- Flight Software Test Plan
- Mongoose C&DH & RSN’s
  - Separate Software Specifications that provide: Requirements, Design, User’s documentation
  - Authored by the Software Developer and reviewed by the software team
  - All 1773 Bus interfaces are being captured as appendices to a single 1773 Bus ICD
- ACS
  - ACS Software Requirements Document
  - ACS Software ICD
  - ACS Software User’s Guide
- All documentation is available on the Flight S/W WEB Page

Configuration Management

- Flight Software CCB established to review all changes
  - Chaired by Flight Software Lead Engineer
  - Includes: CM Officer, C&DH S/W Lead, ACS S/W Lead, Testing Lead.
  - Also draws inputs from developers and other MAP subsystems as needed
- Proposed changes affecting missions requirements, cost or schedule will be forwarded to the MAP project level CCB
- All flight software changes will be approved by the Flight Software CCB prior to Spacecraft I&T
- Flight Software change process is managed by MAP Project CCB once I&T begins.

Configuration Management Tools

- Documentation configured on Web page
- Web based Discrepancy Report (DR) database system to track software changes to closure
- Web based Submit for Test (SFT) database system to track all submissions into CM
- All configured builds will be stored on-line or backed up to easily retrievable media.

Networked Configuration

- Flight Software is stored on a Network Server
  - Nightly backups
  - Regular Off-Site storage of backup media
- Directory structure accommodates all phases of the project lifecycle
  - Development Area (developer access)
  - Test Area (write protected)
  - Configured Area (write protected)

Verification Approach (4 Phases)

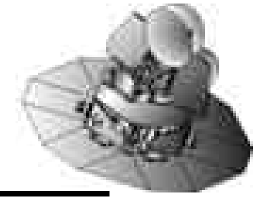
1 **Unit Testing**

- **Goal** is to verify the logical flow and correctness of the software using PC tools
- Unit testing is performed by the Software Developer
- RSN - UTMC69R000 PC Simulator
- Mongoose - Windows 95 Visual C++ Software Bus Simulator
- Occasionally Breadboard hardware is required to verify H/W I/F's

2 **Integration Testing**

- **Goal** is to verify that the software performs properly on the breadboard hardware in the software development lab using the actual embedded system tools
- Integration Testing is performed by the Software Developer
- Build Test Team assists the developer in the verification of all GSE interfaces.

Verification Approach (cont.)



3 Build Testing

- **Goal** is to verify that the software meets all the requirements
- Performed by Build Test Team at the end of each software release
  - MAP S/W Testers
  - Flight Operation Team
  - ACS Analysts
- Requirements Traceability Matrix maintained
- Build Test procedures formally reviewed
- Where possible build tests will be re-used from XTE/TRMM

Verification Approach (cont.)

4 **Acceptance Testing**

- **Goal** is to verify the most important aspects of the Flight Software as a system. Focusing on operational scenarios with all software functions, monitoring, and responses enabled.
- Performed by Build Test Team at the MAP ETU Lab
- Build test team will take selected build tests and various mission scenarios in order to develop a series of acceptance tests
- MAP Systems will assist in the development of acceptance tests
- Acceptance Test Plan will be independently reviewed

Flight Software Maintenance

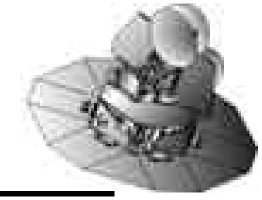
- MAP Flight Software Development Team will be responsible for maintaining the flight software
- 2 Part-time team members will be allocated to this function:
- Flight Software Maintenance will take place in the MAP ETU facility
- ASIST GSE is being enhanced to support flight software maintenance.
  - Table editing and reloading through graphical pages
  - Graphical displays of processor memory images

Reprogramming In Flight

- **RSN Processors**
  - Programming of EEPROM is NOT supported
    - Too dangerous due to risk of corrupting critical applications (safehold, transponder, PSE)
  - Memory patching in RAM is supported
  - Permanent RSN software patches can be stored in the MAC and reloaded autonomously

- **Mongoose Processor**
  - Programming of EEPROM is supported
  - Boot PROM mode provides safe mechanism to program EEPROM's
  - Reconfigurable Tables (RAM & EEPROM)
  - Memory patching in RAM & EEPROM is supported
  - Permanent software patches can be stored in EEPROM

Processor Resource Estimates

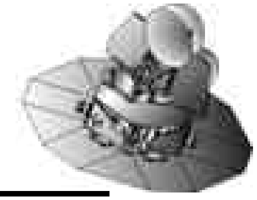


Flight Software

Processor	CPU Rate/Estimate	Boot PROM Avail/Estimate	EEPROM Avail/Estimate	RAM Avail/Estimate	Data RAM Avail/Estimate RSN Only
Mongoose	12.5 Mhz / 60%	256k / 55%	4 Mb / 56%	32Mb / 25%	N/A
PSE RSN	12Mhz / 65%	32k / 8%	128k / 20%	32k / 69%	32k / 40%
ACE RSN	12Mhz / 43%	32k / 8%	128k / 57%	128k / 49%	32k / 66%
XRSN	12Mhz / 30%	32k / 8%	128k / 25%	32k / 59%	32k / 28%
HK RSN	12Mhz / TBD < XRSN	32k / 8%	128k / TBD < XRSN	32k / TBD < XRSN	32k / TBD < XRSN
Instrument RSN	12Mhz / 50%	32k / 8%	128k / <22%	32k / 68%	32k / 69%

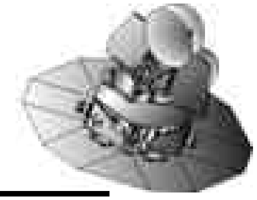
Insert Schedule Here

Conclusions



- Requirements are well understood and documented
- Significant amount of the software is based on previous missions with proven heritage
- Software development effort progressing
  - C&DH Build 1 currently being integrated in the lab. Command, Telemetry, and 1773 Bus software operational
  - PSE RSN Software currently being tested on the ETU
- Flight Software team has sufficient resources to meet our project milestones

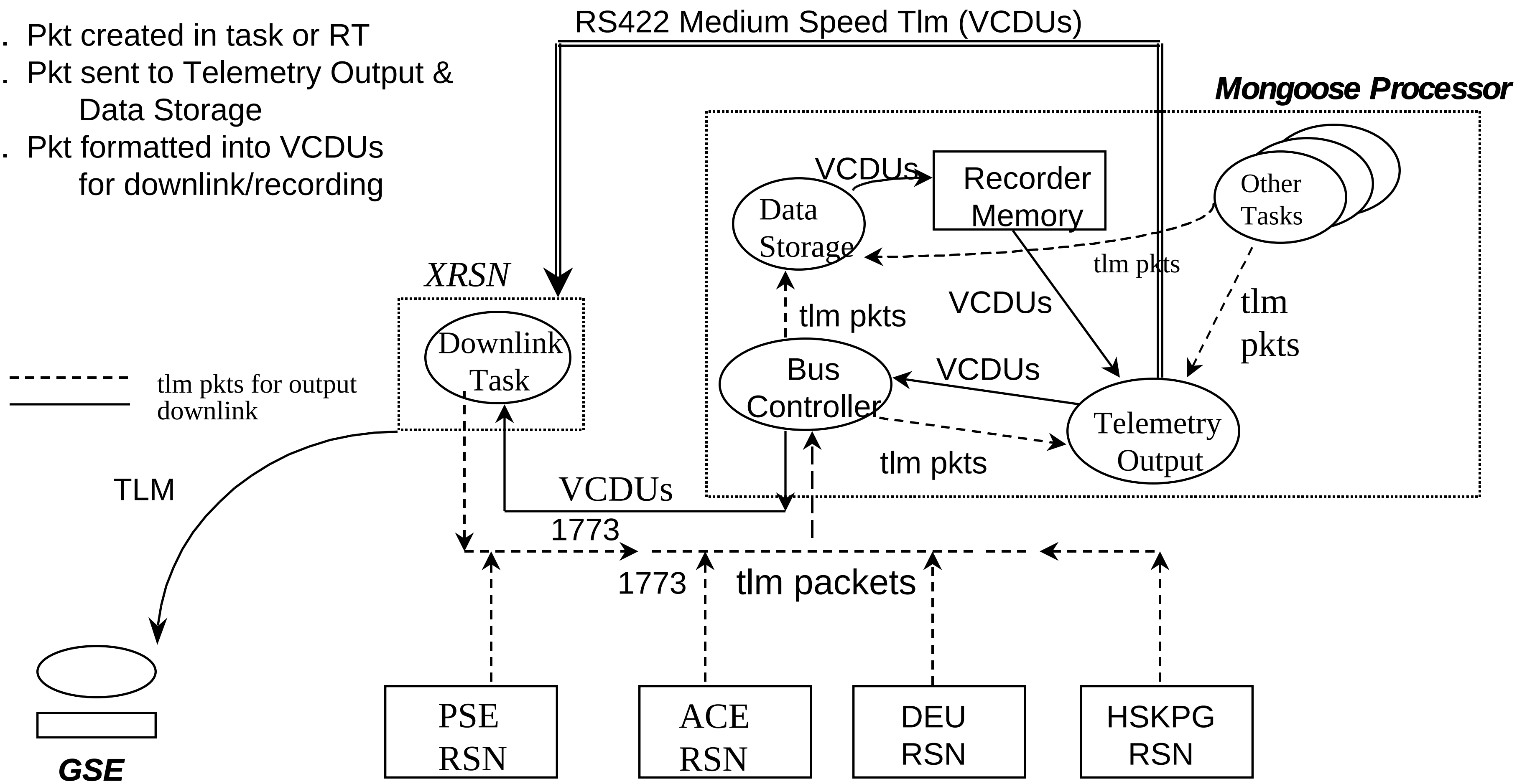
Flight Software Backup Slides



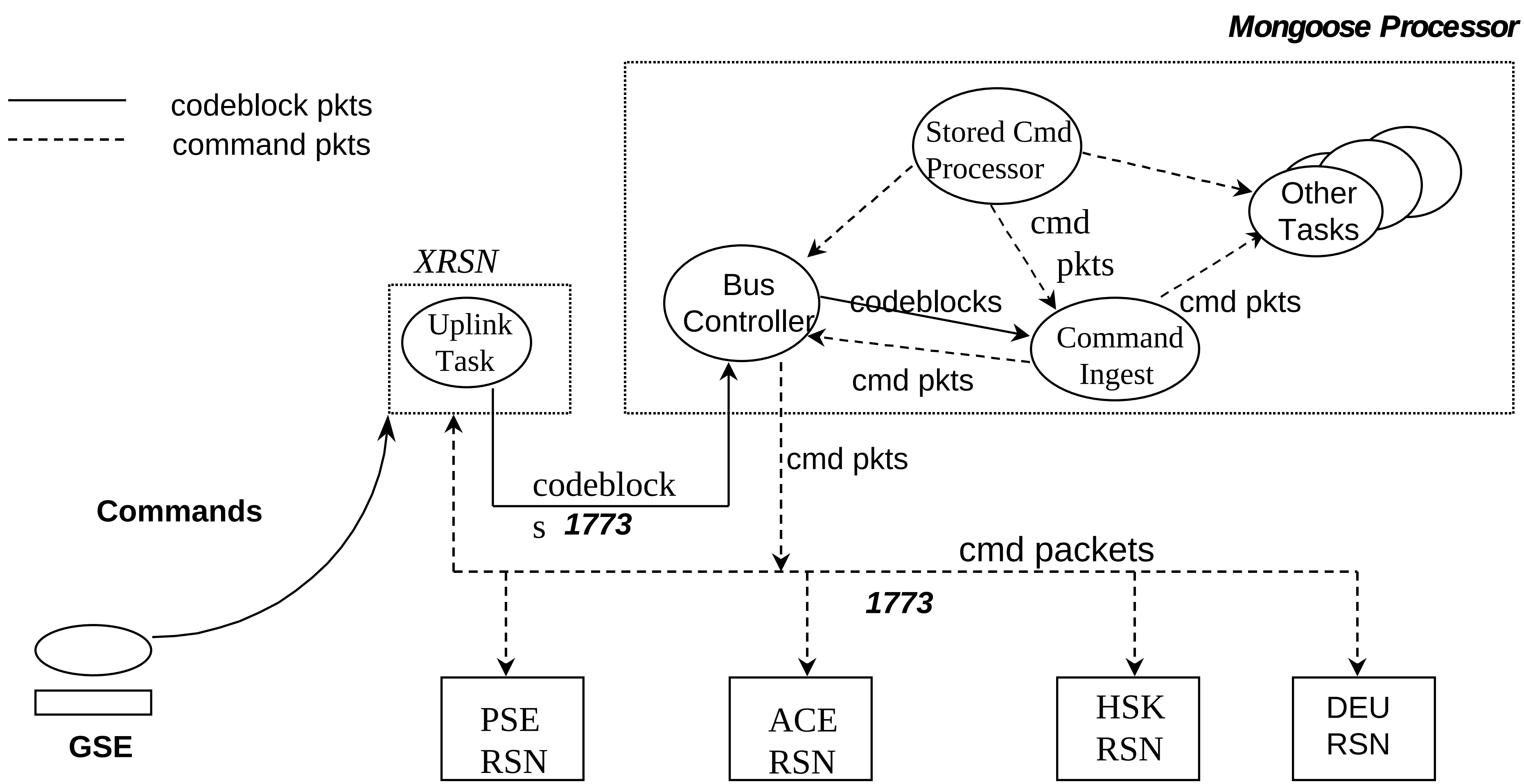
Telemetry Data Flow

Flight Software

1. Pkt created in task or RT
2. Pkt sent to Telemetry Output &
   Data Storage
3. Pkt formatted into VCDUs
   for downlink/recording



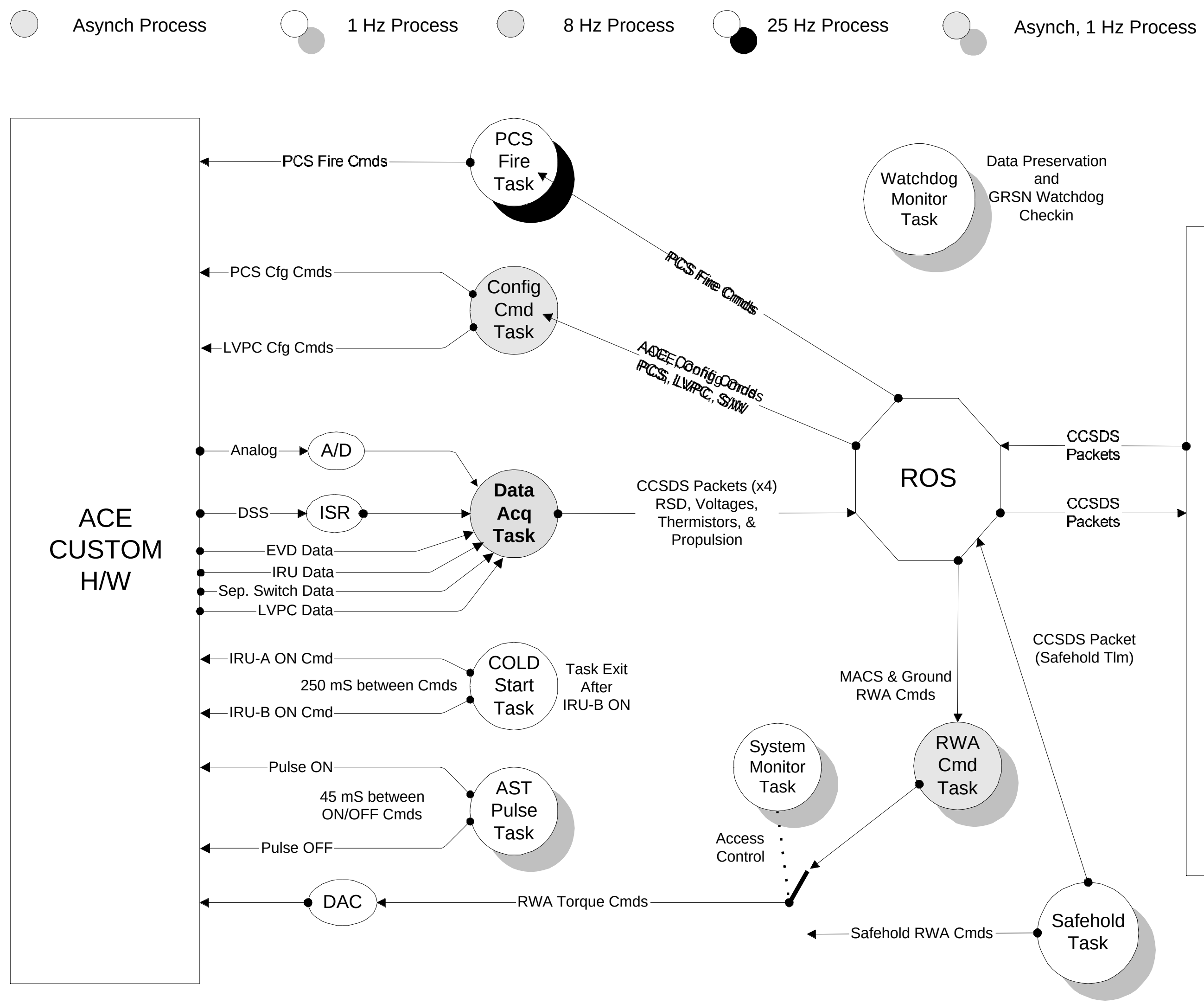
Command Data Flow



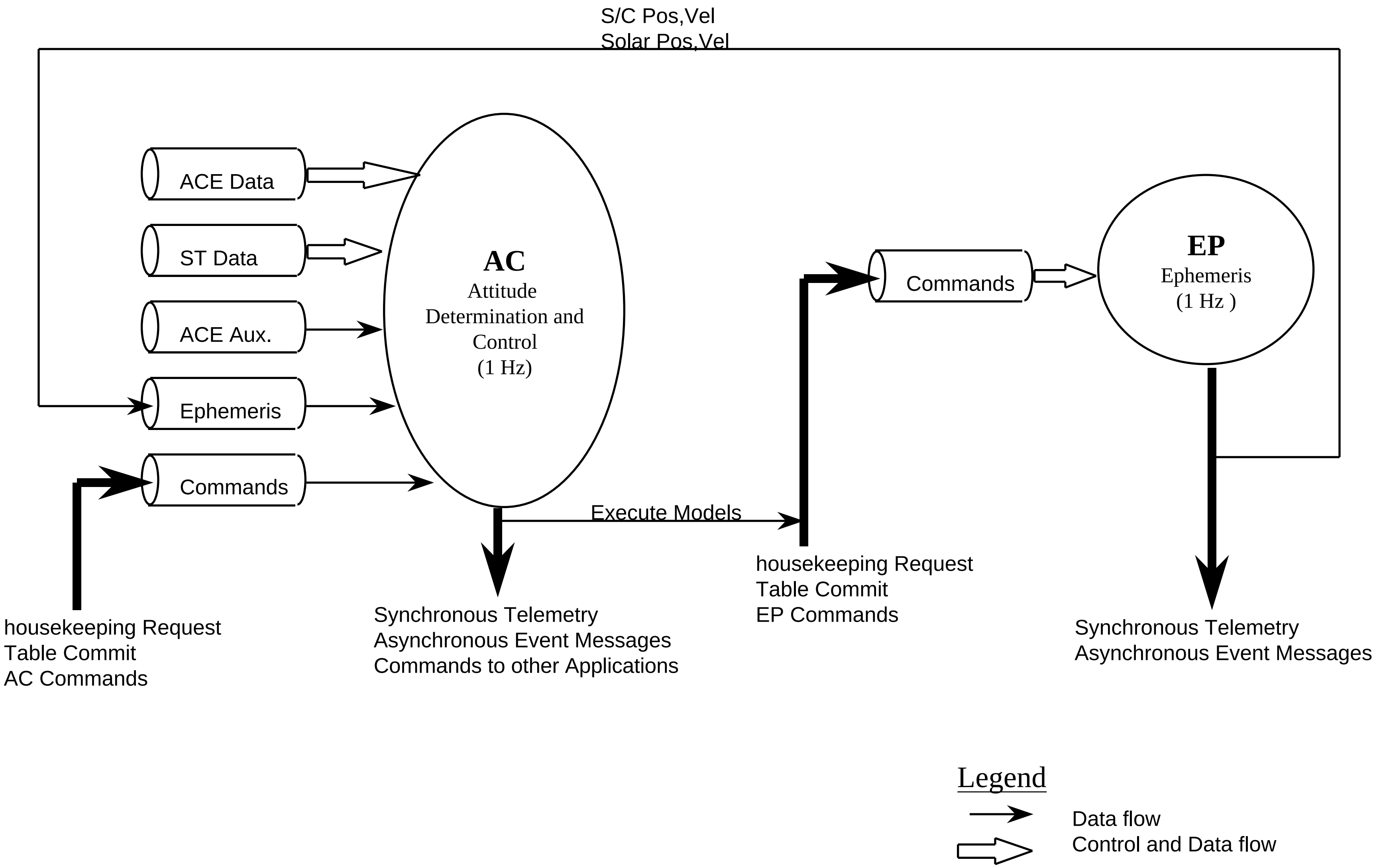
Time Distribution

- Bus Controller (BC) broadcasts a tone message (1 HZ)
  - » BC & all RT's latch the time that the tone message was received
  - » BC reads H/W latch containing time of tone
  - » Broadcasts time of tone to RT's
- RT's adjust their time using the tone delta
- Time can be automatically adjusted to account for oscillator drift
- 64-bit time format: 32 bits seconds, 32 bits subseconds

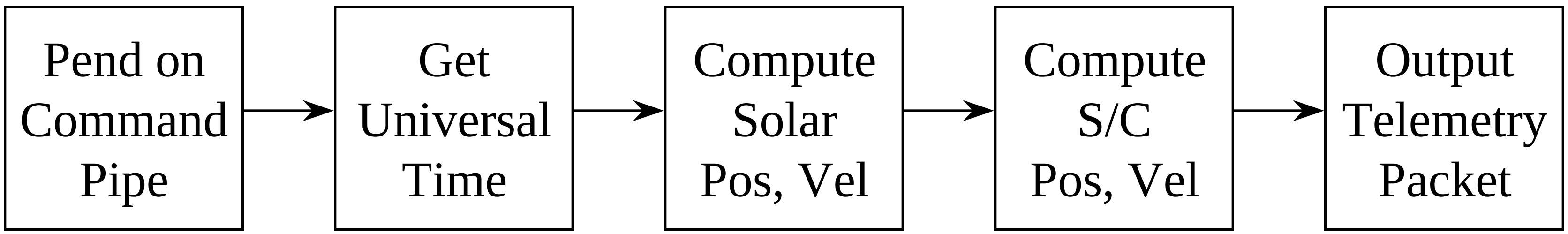
ACE Software Design



Mongoose ACS- Tasking Model



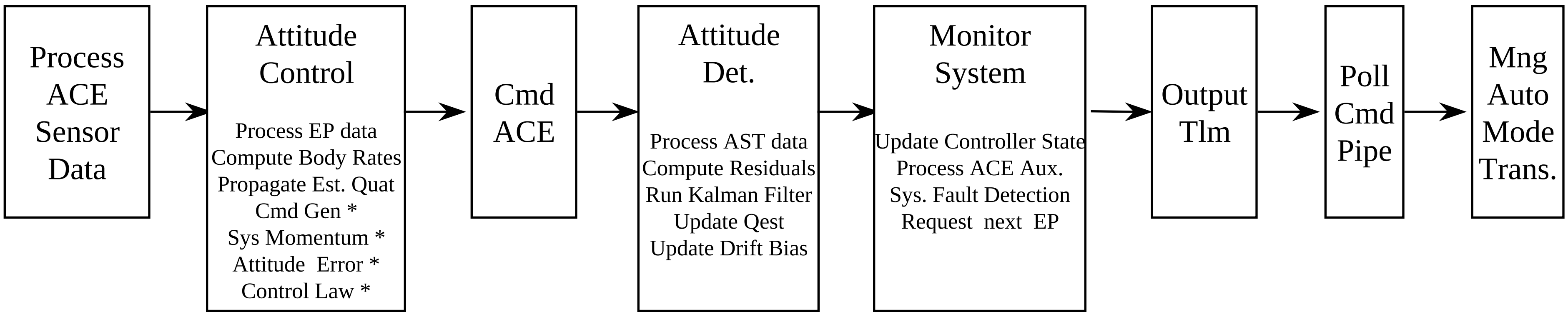
Mongoose ACS Software Design
Ephemeris Task



<u>Notes</u>

- The spacecraft ephemeris may require a lunar ephemeris model.
- The Solar position model is being reused from XTE.

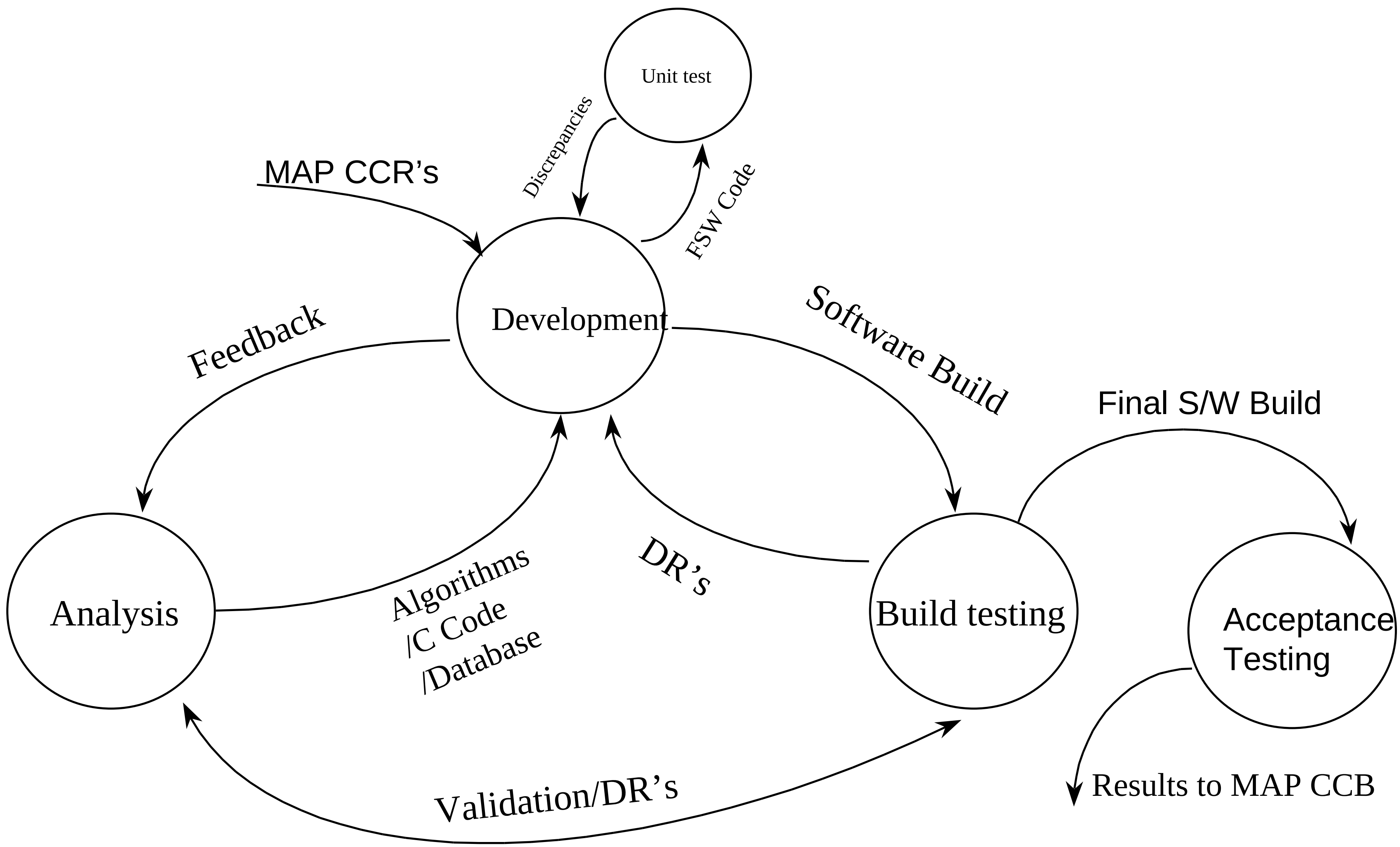
Mongoose ACS Software Design - Attitude Determination & Control Task



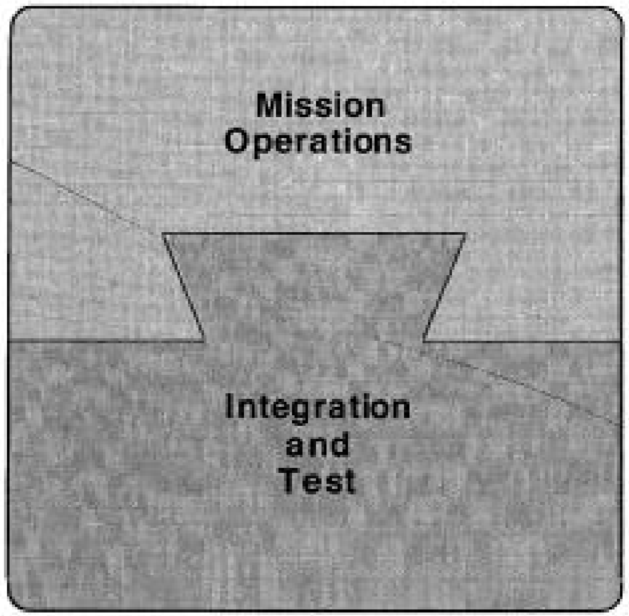
* AutoCode from analyst's block diagrams

ACS Software Development Process

Flight Software



MAP Ground System and Mission Operations

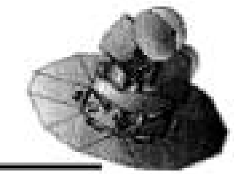


Dovetail to Lower Life Cycle Cost

Agenda

- **Requirements**
  - Level 1 Requirements Flow
  - Interfaces
  - Process Improvements
- **Control Center Concept**
  - End to End Data Flow
  - Combined Ground System
  - Level Zero Processing
- **Spacecraft Controller Team**
  - Roles and Responsibilities
  - Staffing Plan

Ground System Requirements Summary

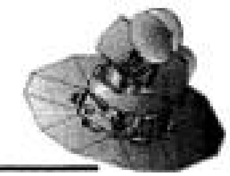


- **Ground stations to receive, process, and route science and HK data to and Commands from GSFC**
  - S-band: Receive data at selected rates up to 666 Kbps and route 2 Kbps commands to spacecraft
  - Implementing the ACE SFDU interface with DSN
    - Route selected virtual channels to GSFC in real time, and FTP recorded data to GSFC within one hour. Store raw data for 30 days.
    - Science data: record up to 0.6 Gbits of data each day.
    - Housekeeping data: record up to 0.3 Gbits of data each day.

Ground System Requirements Summary (cont)

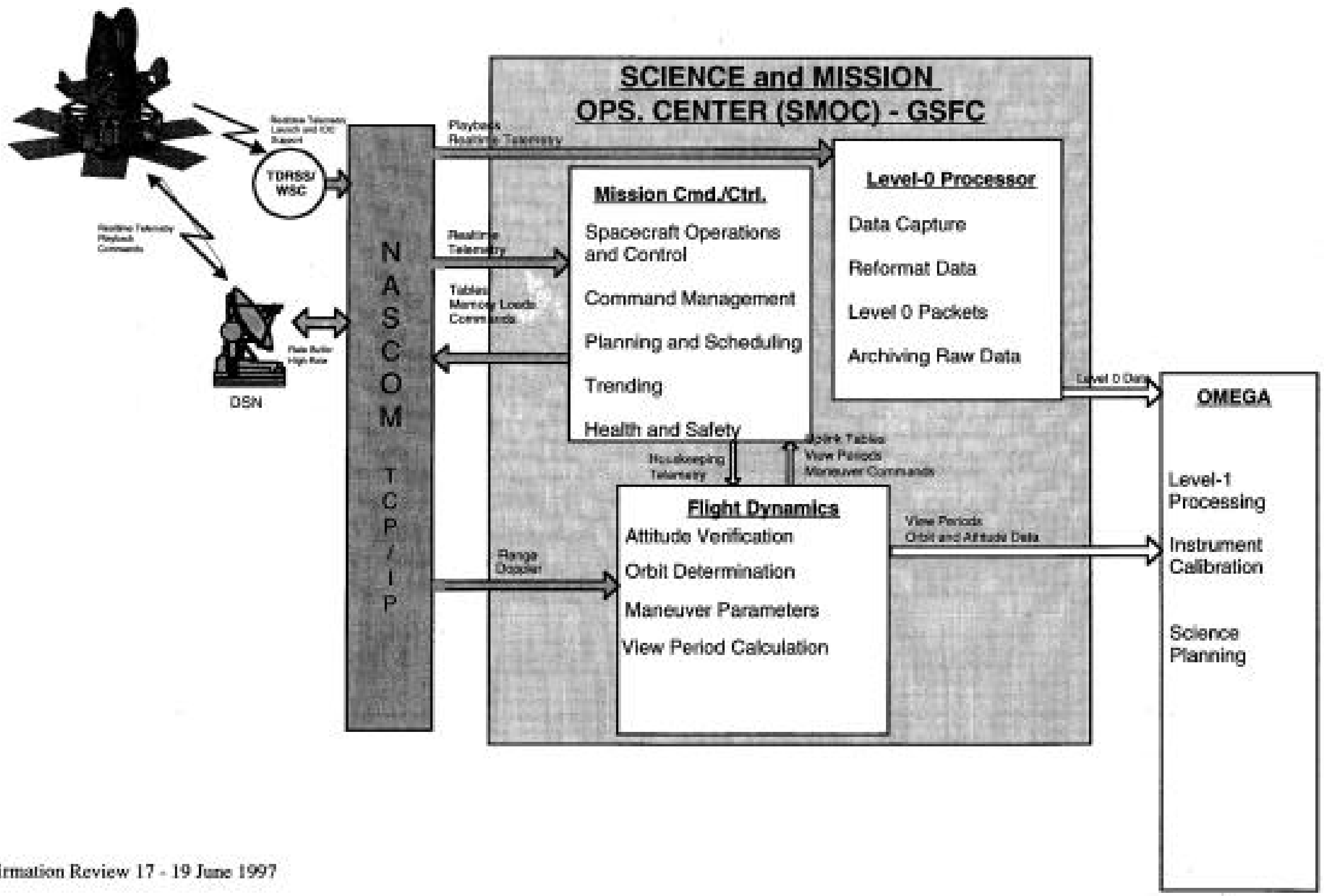
- **GSFC to receive and process data sent from the ground station**
  - Maintain the health and safety of the spacecraft
  - Validate and calibrate onboard attitude subsystem
  - Archive raw data
  - Perform Level-0 processing on the science and HK telemetry
    - Format as received or packet time order
  - Provide mission planning and command management to receive engineering data, build command loads,and schedule ground station support
  - Navigation to L2 and orbit maintenance
  - Produce orbit products

Process Approach and Risk Mitigation



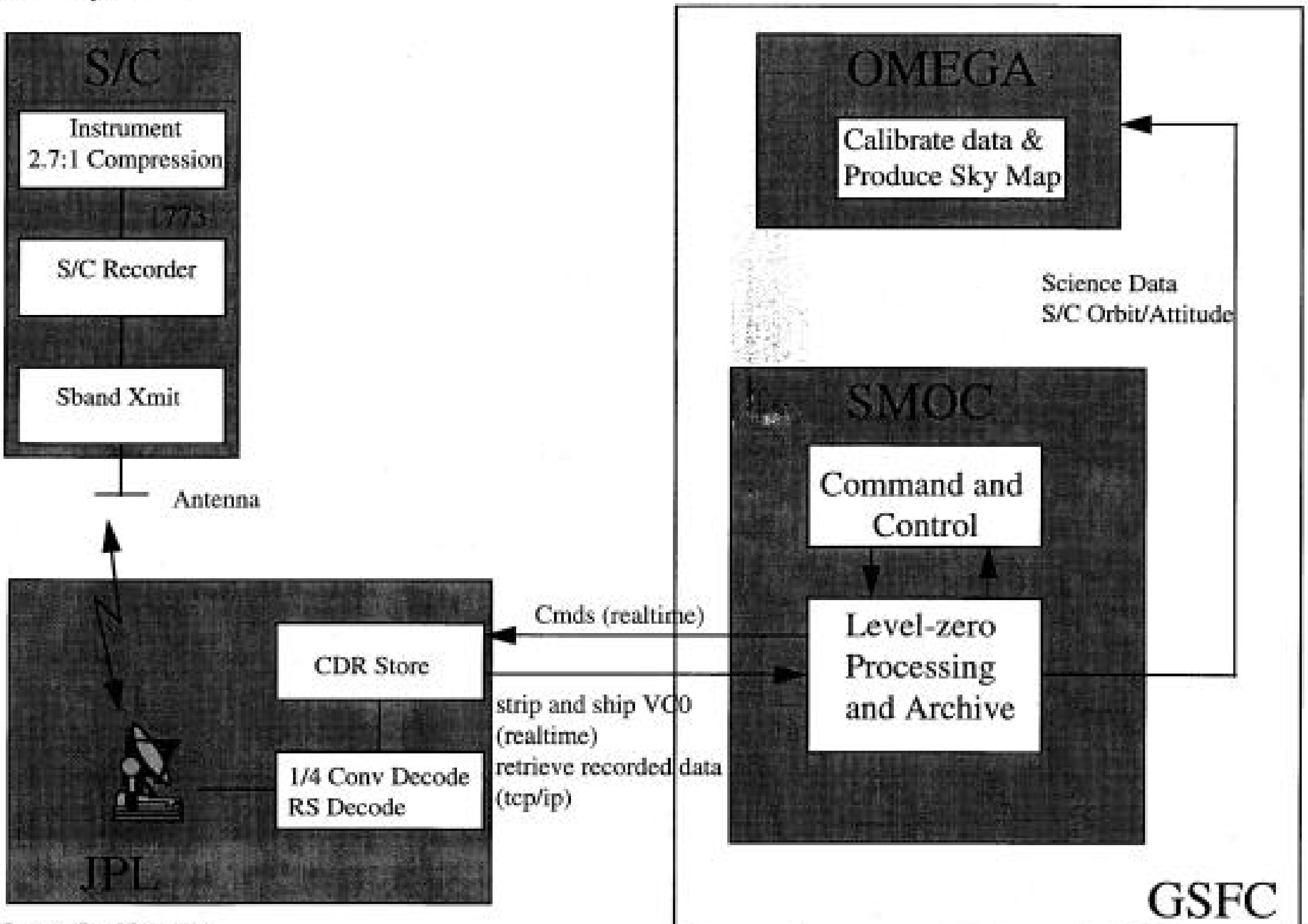
- **Maximize Overlap between I&T and Mission Operations**
- **Reduce Technical, Cost and Schedule Risk of a separate development**
  - I&T Team Transitions to Mission Operations
    - Maximize knowledge transfer between I&T and Operations
    - Minimize Missions Operations Training
  - Combined I&T and Mission Operations Control System
    - Minimize Compatibility Testing with Spacecraft
    - System is tested during the normal course of S/C I&T
    - External Interfaces tested during Mission Simulations

MAP GROUND SYSTEM

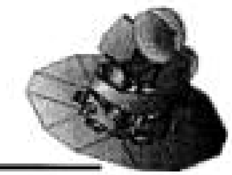


End to End Data Flow

Ground System



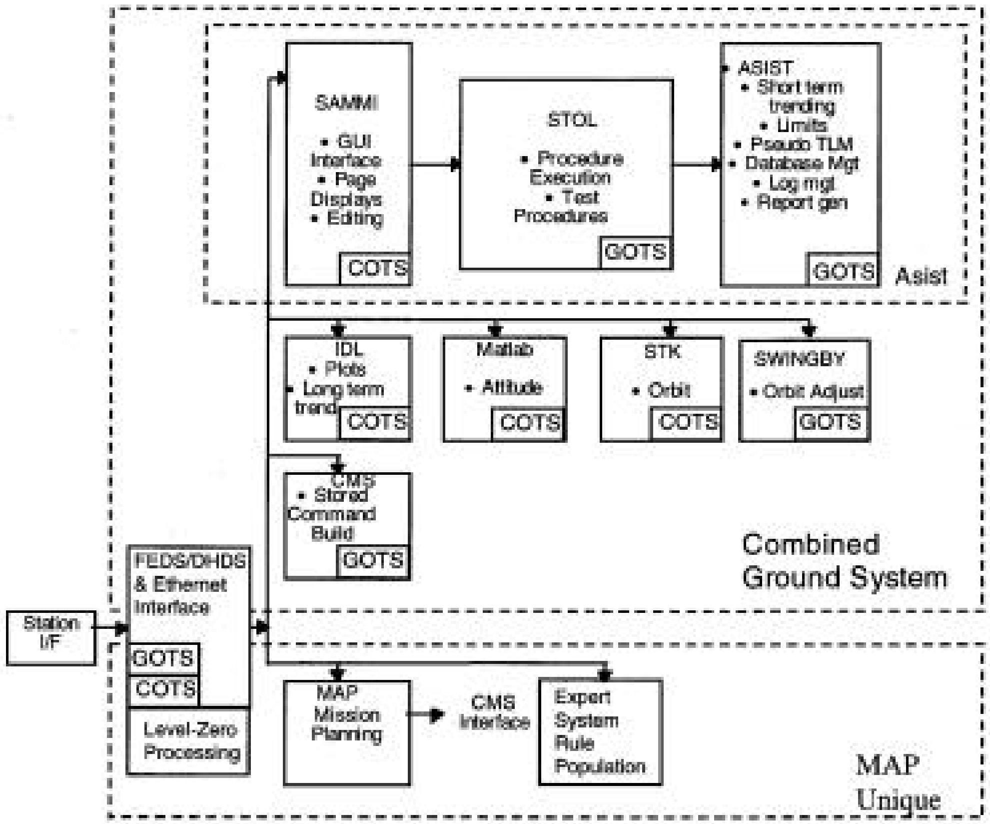
Combined Ground System



- System supports I&T / Mission Operations from component development through termination of Mission Operations.
- Comprised of user selected set of on & off line S/W systems.
- All elements are: Government Off The Shelf Software (GOTS) or Commercial Off The Shelf Software (COTS).
- Mission proven GOTS provided by GSFC Codes 700 and 500.
- Vast majority of MIDEX spacecraft differences are reflected in database definition.
- Mission Unique Software is kept to a minimum.
- 100% COTS hardware

Combined Ground System Diagram

Ground System



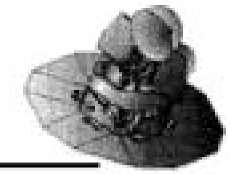
Combined Ground System (ASIST)

- **The Advanced System for Integration and Spacecraft Test (ASIST) provides a distributed human / machine I/F**
  - to the spacecraft and it's components
  - to the spacecraft GSE
  - hosted on IBM R/S 6000
- **ASIST satisfies nominal on and off line spacecraft support requirements for all phases of a mission**
- **Internal/external interfaces are CCSDS compliant**
- **Provides a consistent user interface from component development**

Combined Ground System (ASIST)

- **Database driven command, telemetry and GSE control**
- **Script driven test procedures using the Spacecraft Test and Operations Language (STOL)**
- **<u>Heritage</u>: XTE and TRMM I&T and FSW Development**

Combined Ground System (CMS)

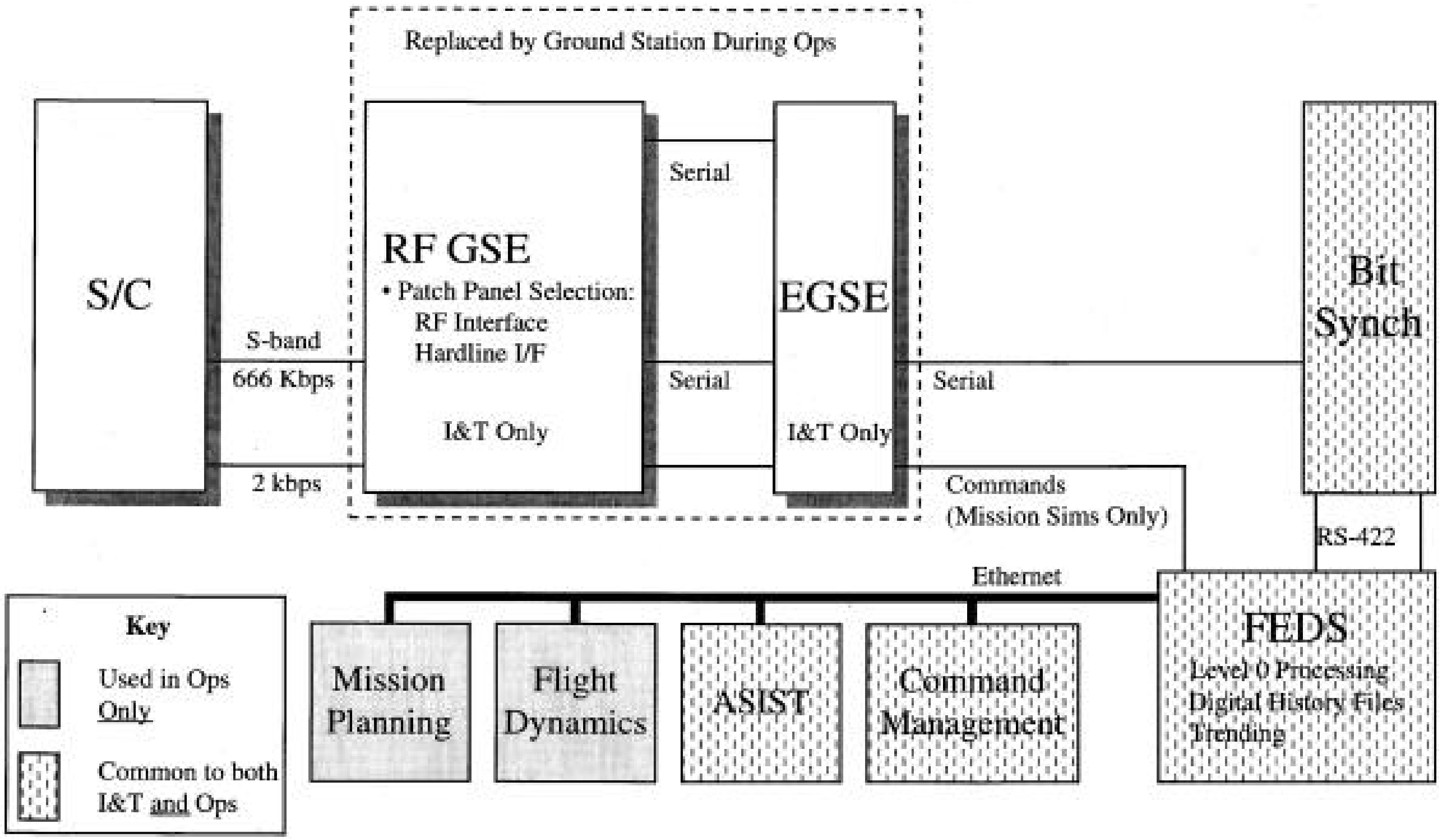


- **Being ported to IBM AIX from HP/UX to support MAP.**
- **The CMS**
  - accepts and validates command input
  - accepts and validates event input
  - creates, validates, generates, and transfers absolute and relative timetag loads
  - generates pass plans
- **<u>Heritage</u>: originally developed to support SAMPEX and has been used to support FAST, TRACE and SWAS.**

Combined Ground System
other major components

- Front End Data System (FEDS) / Digital History Data Storage (DHDS) provide network access to CMD/TLM, ranging data, ground segment status/control and archived data.
- Attitude and orbit determination & control systems are Matlab and STK based.
- The Trend package is based on Interactive Data Language (IDL) and accessible via any network terminal. 100% of the data is available to the trending package.
- Expert System to perform health and safety monitoring of spacecraft and ground segment.
- Pass Planning and Recorder Management
- Level-Zero Processing

Ground System Lifecycle Commonality



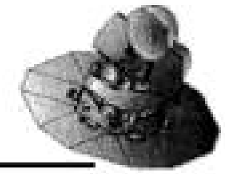
Observatory Test Approach

- **On orbit capability utilized from component development through S/C I&T and Mission Operations**
  - Combined Ground System (CGS)
  - Spacecraft Controller Team (SCT)
  - Spacecraft Development Team (SDT)
  - Documentation, databases and STOL procedures
- **All elements are tested as they will be flown**
- **Modular STOL procedures developed from component test**
- **STOL procedures support system testing and operations**
- **Ground System Verification matrix and Database maintained from component level**

Ground System Test Approach

- **Ground System Software Release Tests**
  - Development Team unit tests prior to release
  - Pre-release testing and evaluation is performed informally by the SCT
  - Released version is evaluated by the SCT prior to wide distribution
    - Tested at non-critical site (i.e. breadboard equipment)
    - Test Plans are operationally oriented
    - Plans are authored and executed by the SCT
  - Full distribution coordinated with each site
  - S/C I&T continuously verifies 90% of Ground System requirements and entire system verified during mission simulations
  - Requires End-to-End Tests & Mission Simulations to fully verify functionality & performance

Spacecraft Controller Staffing



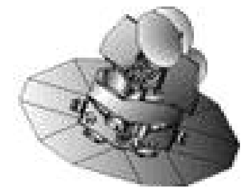
- **The Operations concept for the SCT executed in three distinct phases:**
- **Launch and In-Orbit Checkout to Lunar fly-by and Mid-course correction (MCC).**
  - The SCT supports at a high level, 24 hours a day for the first 50 days to ensure all initial activation operations and manuevering go smoothly.
  - 3-12 hours of contact time/day
  - Key members of SDT serve in the SMOC until staffing needs decrease.
- **Lunar fly-by and MCC to L2 - Transition to a smaller staff and more autonomous operations.**
  - SMOC will be manned by the SCT 16 hours a day.
  - 2-3 hours of contact time/day

Spacecraft Controller Staffing

- **L2 months to EOM - Reduce the team and automate operations where possible.**
  - SMOC will be manned 8 hours a day.
  - One 37 minute contact/day
  - Automation systems will execute the contact pass plans, assess state of health, perform all commanding (with the exception of Special and Contingency Events) and initiate Level 0 processing and trending.

Operations Documents

Title	Due	Status
Mission Requirements Request		Final
Operation Concept Document		Final
Mission Operations Plan	CDR	
Detailed Mission Requirements	6/97	
Ground System I+T Plan	6/97	Draft
Ground Station ICD		
(appendix to GSFC-JPL ICD)	12/97	
OMEGAICD	6/97	
Launch & IOC Plan	L-12 mo	
Mission Ops Contigency Plan	L-6 mo	
Mission Ops Procedures	L-6 mo	

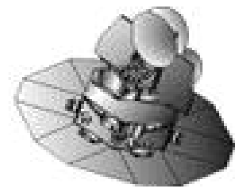


MAP Validation Plan

6/19/97

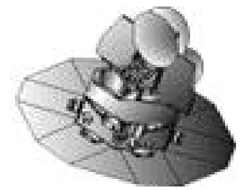
updated 8/9/99

Presenation Organization



- Background
- Roadmap
- Flight Readiness Flow
- Confirmation Review Verification Presentation

Background



- Mission Integration and Verification Plan presented at the Confirmation Review 6/19/99
  - Covers system level environmental and performance verification
- ISO requires a ***validation*** plan
  - Essentially the same as what we have called verification
  - Required for all “products” (subsystems) as well as system
- Updated Confirmation Review Package (this package) responds to ISO requirements

Roadmap

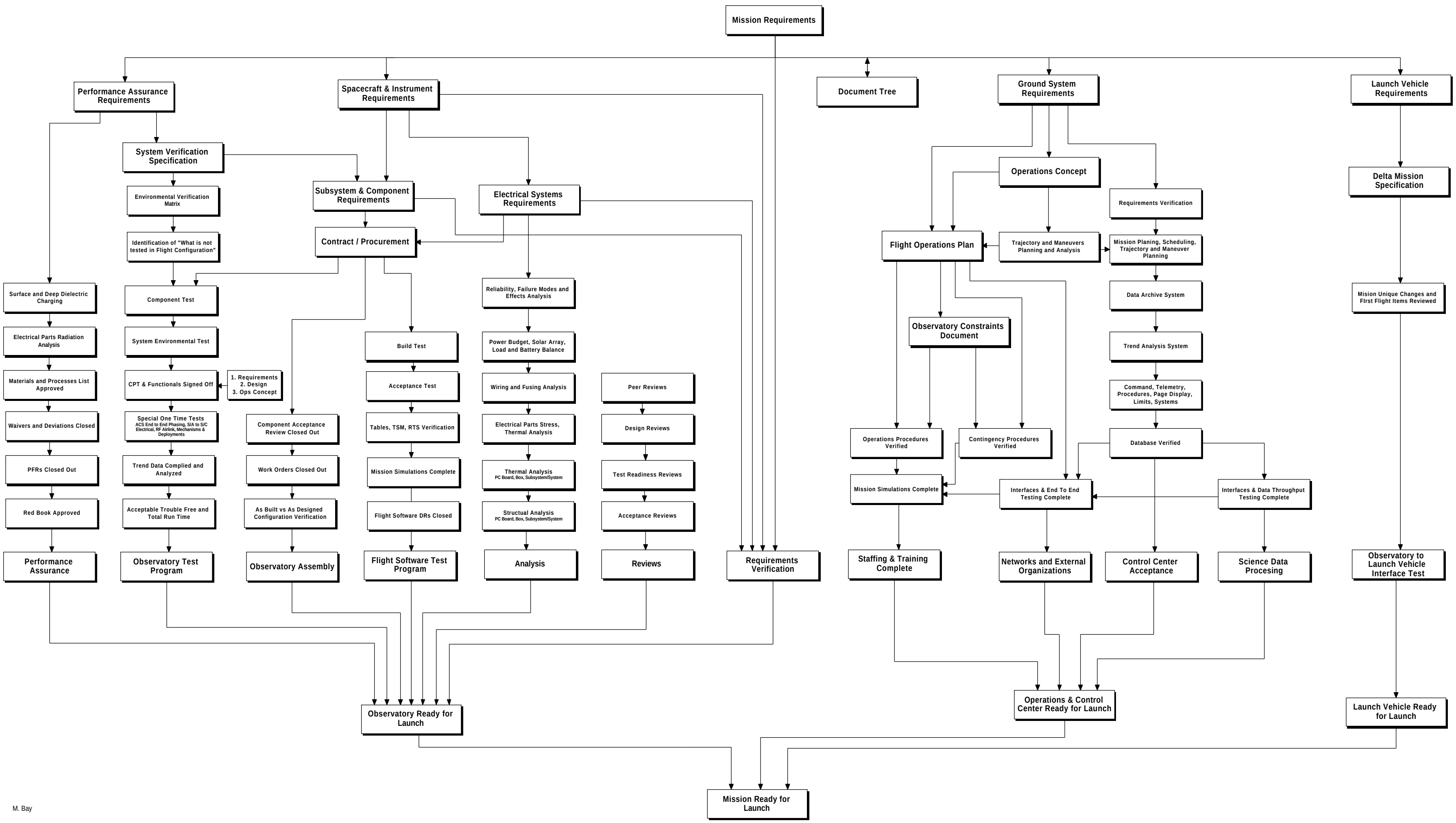
- MAP Flight Readiness Flow
  - Shows all activities and associated documentation that must be successfully completed to to achieve launch readiness
  - Includes validation activities
- Subsystem (Product) Validation Planning
  - Project philosophy and approach documented in PDR and CDR presentations
  - Subsystem specific activities documented in PDR and CDR presentations and Peer Reviews

Roadmap (cont.)

- Environmental Verification
  - Specific system and subsystem requirements documented in MAP Environmental Verification Plan
  - Environmental test matrix maintained by Verification Engineer

MAP Flight Readiness Flow

8/4/99



M. Bay

Mission Integration and Verification

L. Citrin and C. Jackson

MAP
Integration and Verification

Presentation Organization

- Mission Verification Approach Overview
- Observatory Integration Flow Overview
- Instrument I&V Plan
  - Environmental Verification Overview
  - Performance Verification Overview
  - Integration/Verification Flow
- Spacecraft/Observatory I&V Plan
  - Environmental Overview
  - Performance Overview
  - Integration/Verification Flow

MAP

Integration and Verification

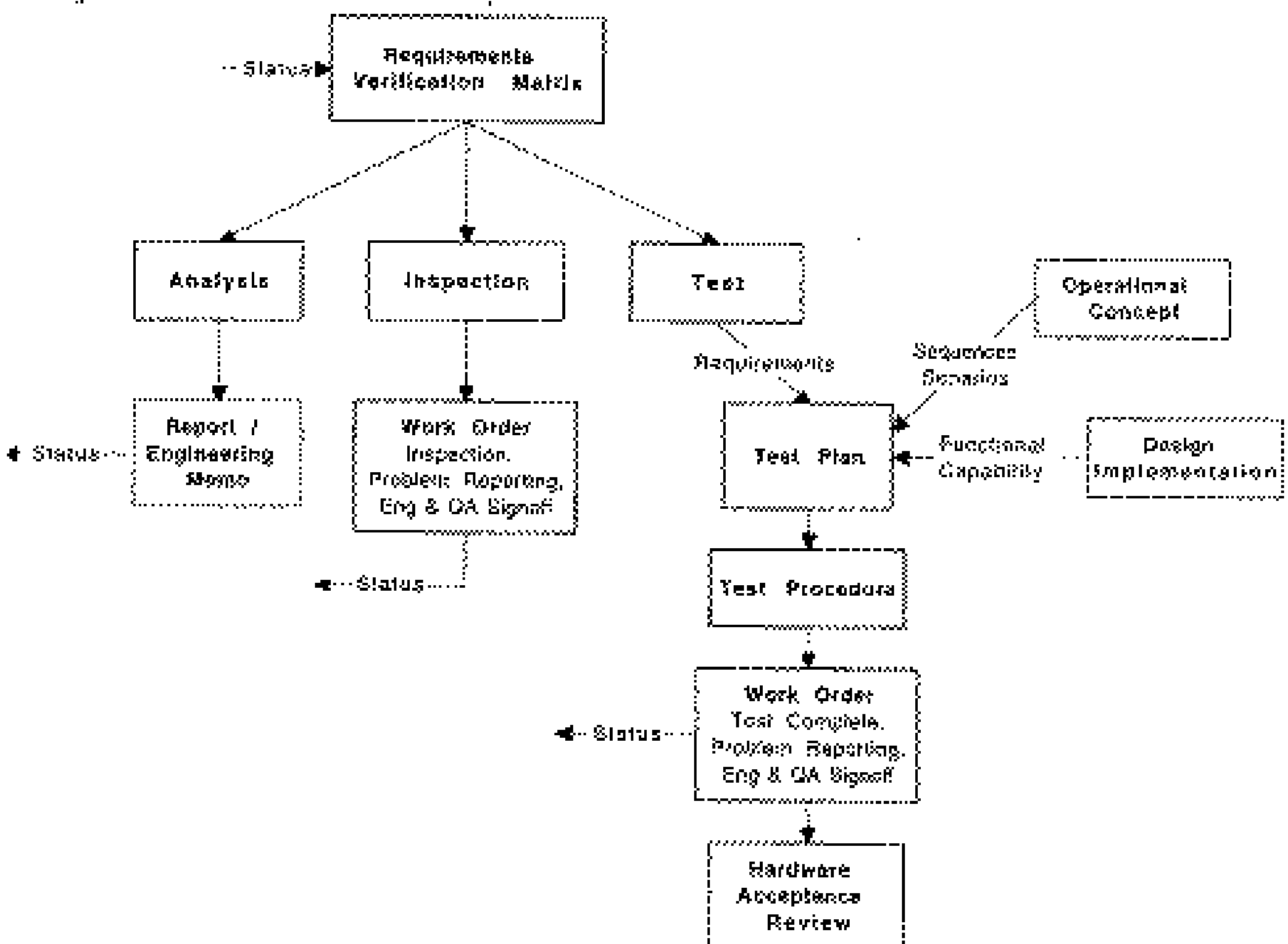
Verification Approach

- All mission level requirements and derived subsystem requirements must be verified by test, analysis, similarity, and/or inspection
- All planned on-orbit operations are verified via ground test and simulation
- Test procedure execution and test results are tracked via a formal work order and failure reporting quality assurance process
- Sufficient ground test time (2000 + hours) will be accumulated to screen out the infant mortality failures and to trend key performance parameters
- ETU's, BB, LNVU's, Evaluation Unit hardware developed for early interface verification
- Trending of key performance parameters starts at component development and continues throughout I & T
- Environmental test program includes prototype, protoflight & flight hardware tested in accordance with GEVS guidelines, augmented with mission unique science requirements

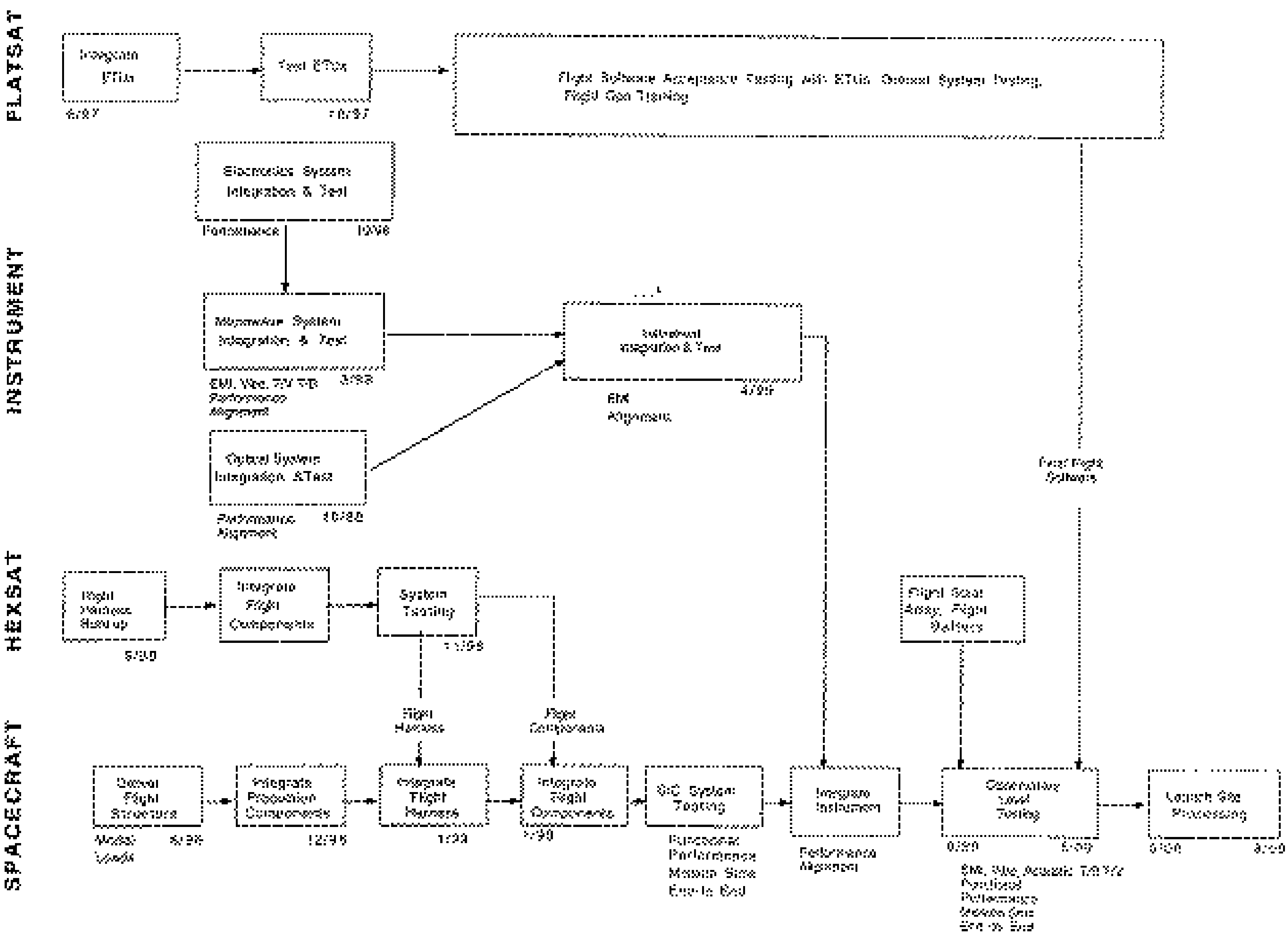
MAP

Integration and Verification

Requirements Verification Flow



MAP System Integrati & Verification Flow



25-Apr-97

MAP ENVIRONMENTAL VERIFICATION MATRIX

LEVEL OF ASSEMBLY	ITEM	UNIT TYPE	QUANTITY	TESTS AND ANALYSES	COMMENTS
O	MAP Observatory	[illegible]	1	[illegible]	
S	Spacecraft Structure	[illegible]	1	[illegible]	
X	Attitude Control Subsystem			[illegible]	
C	Reaction Wheels	[illegible]	3	[illegible]	[illegible]
C	Reaction Wheel Electronics	[illegible]	1	[illegible]	
C	Digital Sun Sensor	[illegible]	1	[illegible]	[illegible]
C	Digital Sun Sensor Electronics	[illegible]	1	[illegible]	
C	Coarse Sun Sensor	[illegible]	[illegible]	[illegible]	
C	Star Tracker	[illegible]	1	[illegible]	
C	Inertial Reference Unit	[illegible]	1	[illegible]	
X	Power Subsystem				
C	Power Supply Electronics	[illegible]	1	[illegible]	
C	Power Supply Electronics	[illegible]	1	[illegible]	
C	Battery	[illegible]	1	[illegible]	[illegible]
C	Solar Panels	[illegible]	[illegible]	[illegible]	
C	Solar Array Hinges	[illegible]	[illegible]	[illegible]	[illegible]
A	Solar Array Release Mechanism	[illegible]		[illegible]	[illegible]
X	RF Communication Subsystem				
C	Transponder	[illegible]	2	[illegible]	
C	Diplexer	[illegible]	[illegible]	[illegible]	
C	Omni Antenna	[illegible]	[illegible]	[illegible]	
C	Omni Antenna	[illegible]	[illegible]	[illegible]	
C	Medium Gain Antenna	[illegible]	[illegible]	[illegible]	
C	Medium Gain Antenna	[illegible]	[illegible]	[illegible]	
C	RF Switches	[illegible]	[illegible]	[illegible]	
C	RF Cable			[illegible]	

[illegible]

[illegible]

MAP ENVIRONMENTAL VERIFICATION MATRIX

LEVEL OF ASSEMBLY	ITEM	COMMENTS
[illegible]	Radio Subsystem	
[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]
[illegible]	Star Scanner	
[illegible]	Star Tracker	
[illegible]	Propulsion Subsystem	
[illegible]	Propellant Tank	[illegible]
[illegible]	Thrusters	
[illegible]	[illegible]	
[illegible]	Liquid Fill/Drain Valve	
[illegible]	Liquid Fill/Drain Valve	
[illegible]	Gas Fill/Drain Valve	
[illegible]	Gas Fill/Drain Valve	
[illegible]	Pressure Transducer	
[illegible]	Isolation Valve	
[illegible]	Propellant Filter	
[illegible]	Tubing	
[illegible]	Brackets	

[illegible]

[illegible]

MAP ENVIRONMENTAL VERIFICATION MATRIX

LEVEL OF ASSEMBLY	ITEM	MODEL TYPE	QUANTITY	THERMAL ANALYSIS	STRUCTURAL ANALYSIS	PERFORMANCE/FUNCT.	MODAL SURVEY	LOADS TEST (1)	SINE SWEEP (2)	RANDOM VIBRATION	SHOCK	MECHANICAL FUNCTION	ACOUSTICS	LEAK TEST	MASS PROPERTIES	PRESSURE PROFILE	[illegible]	[illegible]	THERMAL VACUUM (3)	THERMAL BALANCE	THERMAL CYCLING	[illegible]	[illegible] TEST	COMMENTS
I	MAP Instrument	PF	1	G	G	P											G*							* [illegible]
S	Microwave System	F	1	G	G				G						G		G		G	G				[illegible]
C	Microwave Structure	PT	1	G	G			G	G	G					G				G	G				[illegible]
C	Microwave Structure	F	1	G	G																			
C	Feeds	F	20	G	G	P																		[illegible]
S	[illegible] Assemblies [illegible]	F	10	G	G	P			G	G									P					[illegible]
S	[illegible] Assemblies [illegible]	PT	1	G	G	P		G	G	G														[illegible]
A	[illegible]	F	20	G	G	V																		
A	[illegible] Waveguides	F	40	G	G	P/V																		
A	[illegible]	F	20	G	G	V																		
P	HEMT Amplifiers	PT	2	G	G	V		G	G	G									E					[illegible]
P	HEMT Amplifiers [illegible]	F	80	G	G	V				G									V					[illegible]
A	Phase Matched Waveguides	PT		G	G	P/V																		[illegible]
A	Phase Matched Waveguides	F	40	G	G	P/V																		
P	Phase Switches	F	40	G	G	V															V			
A	Phase Switch Driver [illegible]	F	10	G	G	G															V			
A	[illegible]	F	20	G	G	V																		
A	[illegible] Filters	F	40	G	G	V																		
P	[illegible] Diode Detectors	F	40	G	G	V																		
A	[illegible]	F	40	G	G	G															V			
	Microwave [illegible]	F				P/V																G		
S	Thermal Reflector System	PT	1	V	V	V	V	V	V				V		V				V	V				* [illegible]
S	Thermal [illegible] System [illegible]	PT	1	V	V	V																		[illegible]
C	[illegible] Structure	PT	1	V	V	V																		
C	Primary & Secondary Reflectors	PT	6	V	V	V																		
C	[illegible]	PT	2	G	V	V																		
	[illegible]			G	G	G																		
	Thermal [illegible]	F	10	G	G	G																		
S	Electronics Subsystem																							
C	[illegible]	PT	1	G	G	G		G	G	G							G		G					
C	[illegible]	PT	1	G	G	G		G	G	G							G		G					
	Instrument Harness	PT		G	G	G																		

LEVEL OF ASSEMBLY [illegible]
[illegible]

MODEL TYPE [illegible]
[illegible]

VERIFICATION [illegible]
[illegible]

(1) [illegible]
(2) [illegible]
(3) [illegible]

Environmental Test Levels

• Structural / Mechanical	Structural Design and Test Loads for MAP Componenets (MAP-GEM-STRC-001)
• Thermal	Thermal Interface Control Document (MAP-THERM-ICD-001)
• EMI	Electrical Systems Specification (MAP-ELEC-001)

MAP

Integration and Verification

Hardware I & T Facilities

Facility	**Hardware**
• Flatsat (available 6/97-launch+) B29, room 150	• ETU boxes (PSE,MAC,RF) Test harness with flight-like connecters Umbilical Console/ S/C GSE/ PSE GSE
• Hexsat (6/97-5/98 harness build) (6/98-12/98 flight boxes) B29, room 150 hi-bay	• Flight harness buildup Flight boxes (as necessary) Umbilical Console/ S/C GSE/ PSE GSE
• Flight Stucture (available 8/98-12/98)	• Flight propulsion s/s buildup in the Building 7 SCA Cleanroom
• Spacecraft (available 12/98) B29, room 150 hi-bay	• I & T of flight units and harness Umbilical Console/ S/C GSE

Instrument I & V

MAP

Integration and Verification

Instrument Environmental Test Program Overview

- All instrument components are fully qualified prior to instrument integration
- Instrument Level vibration and thermal vacuum/ thermal balance testing are postponed to the Observatory Level to provide more time for testing at the highest level
- The following Prototype hardware will be qual tested early in the program to verify design:
  - HEMT amplifiers to undergo vibration (Q-band) and thermal vacuum testing (Q,V,W band)
  - 1/2 Differencing Assembly (radiometer) to undergo vibration testing
  - The Microwave System structure (MS#3) and all waveguides will undergo vibration and t/v t/b testing (the flight Interface Cylinder is tested in the prototype MS#3)
- Thermal testing
  - goal to acheive at least flight operating temperatures plus margin on all flight hardware
  - +/- 10 degrees warm & cold temperature margins

MAP Instrument Flight Hardware Thermal Cycling

	QUANTITY	CARD LEVEL	BOX/UNIT LEVEL	RADIOMETER LEVEL (PU)	DA LEVEL (PU)	DA LEVEL (GSFC)	MICROWAVE SYSTEM (with [illegible])	MICROWAVE SYSTEM (with [illegible])	TRS LEVEL	INSTRUMENT LEVEL	OBSERVATORY LEVEL
Microwave System Structure	1						2	2			2
Feeds	20							2			2
OrthoMode Transducer (OMT)	20			1	1		2	2			2
Cross Coupling Waveguides	40				1		2	2			2
Magic Tees (cold)	20			1	1		2	2			2
HEMT Amplifiers (warm)	40		2	1			2	2			2
HEMT Amplifiers (cold)	40		2	1	1		2	2			2
Phase Matched Waveguides	40			1	1		2	2			2
Phase Switches	40		10	1			2	2			2
Phase Switch Driver Boards	10		10	1			2	2			2
Magic Tees (warm)	20			1			2	2			2
Bandpass Filters	40			1			2	2			2
Balanced Diode Detectors	40			1			2	2			2
Line Driver Boards	40		10	1			2	2			2
Truss Support Structure	1								1		2
Primary & Secondary Reflectors	4								1		2
Radiator	2								1		2
MLI Shields								1	1		2
Thermal Straps	10						2	2	1		2
AEU/DEU	1		8				2	2			2
PDU	1		8				2	2			2
Microwave Absorber							2	2			2
Instrument Harness	1						2	2			2

NOTE: Cycling performed in vacuum except where shaded

MAP Instrument Flight Hardware
Structural Testing

	QUANTITY	CARD LEVEL	BOX/UNIT LEVEL	RADIOMETER LEVEL (PU)	DA LEVEL (PU)	DA LEVEL (GSFC)	MICROWAVE SYSTEM (WITH OMT LOADS)	MICROWAVE SYSTEM (WITH FEED/[illegible] LOADS)	TRS LEVEL	INSTRUMENT LEVEL	OBSERVATORY LEVEL
Microwave System Structure	1							S			S,A
Feeds	20							S			S,A
Orth Mode Transducer (OMT)	20					S,R		S			S,A
Cross Coupling Waveguides	40					S,R		S			S,A
Magic Tees (cold)	20					S,R		S			S,A
HEMT Amplifiers (warm)	40		R			S,R		S			S,A
HEMT Amplifiers (cold)	40		R			S,R		S			S,A
Phase Matched Waveguides	40					S,R		S			S,A
Phase Switches	40					S,R		S			S,A
Phase Switch Driver Boards	10					S,R		S			S,A
Magic Tees (warm)	20					S,R		S			S,A
Bandpass Filters	40					S,R		S			S,A
Balanced Diode Detectors	40					S,R		S			S,A
Line Driver Boards	40					S,R		S			S,A
Truss Support Structure	1								L,S,A		S,A
Primary & Secondary Reflectors	4								L,S,A		S,A
Radiator	2								L,S,A		S,A
MLI Shields								S	L,S,A		S,A
Thermal Straps	10							S	L,S,A		S,A
AEU/DEU	1		R,L,S								S,A
PDU	1		R,L,S								S,A
Microwave Absorber								S			S,A
Instrument Harness	1							S			S,A

R = Random, L = Loads Test, S = Sine Sweep, A = Acoustics

Instrument EMI Test Summary

MAP Integration and Verification

- AEU/DEU and PDU Box Level
  - Radiated emissions and susceptibility
  - Conducted emissions and susceptibility
- Microwave System (with Electronics System) Level
  - Conducted emissions and susceptibility
  - Bus voltage spin stability test
- Instrument Level
  - Radiated emissions and susceptibility
- Observatory Level
  - Radiated emissions and susceptibility
  - Bus voltage spin stability test

Instrument Performance Verification

MAP Instrument: Major Performance Parameters

Integration and Verification

- Systematic Error
  - Per Error Budget and Specifications (Offsets; Sidelobes; dTs, dVs, dIs @ι-Spin; dG/dV, dG/dT, and dG/dI coefficients)

- Spatial Resolution
  - Per Error Budget and Specifications (Instantaneous Beam Size, Beam Pointing Uncertainty, and Beam Smearing)

- Sensitivity
  - Per Error Budget and Specifications (Tsys, Number of Channels, Integration Time, Bandwidth, Responsivity, Noise Spectral Density, Dynamic Range)

- NO CALIBRATION SOURCES TO VERIFY!!!

Systematic Error: Verification per Systematic Error Budget and Specifications

MAP Integration and Verification

Observatory Interfaces

- SS and Spin-sync Observatory Temp Predicts/Msmts. (TRS, MS, Obs T/B)
- ACS Analyses/Tests (wobble and RW power var. @ fspin)
- PSE Spin-sync bus voltage Predicts/Msmts. (PSE, S/C, Obs)
- Instrument Shadowing Predicts/ Msmts. (TRS, S/C Mech, Obs)

#4 Gain Fluctuations (Multiplies the Offset)

- Applies to DAs, and AEU amps
- Spin-sync dI & dV Predicts/Tests (sel. power supplies; PDU)
- dI & dV Sensitivity Predicts/Tests (sel. DA comps; DAs)
- Use Spin-sync Temp Data
- dT Sensitivity Predicts/Tests(PDU, AEU(Again), DA (Δ responsivity))

#5 Offset

- Use SS Temp Data
- Emissivity Predicts
- Emissivity Msmts (sel. comps)
- Offset Msmts. (DA, MS, Obs T/B)

#3 External Emissions (Additive)

- Sidelobes (REU tests; analysis)
- Sun, Earth, Moon inputs (analysis)

#1 Internal Emissions (Additive)

- Emissivity Predicts
- Emissivity Msmts. (per "Offset")
- Use Spin-sync Temp Data
- Spin-sync Temp Bounding

#2 Electronics Sources (Additive)

- Use Spin-sync Temp data
- dT Sensitivity Predicts/Tests (AEU)
- Spin-sync 2500 Hz pickup analyses

MAP

Integration and Verification

Spatial Resolution: Verification per Spatial Resolution Error Budget and Specs

Error Source #1: Instantaneous Beam Size

- YRS Code Verification
- STOP Optical Performance Analyses
- STOP Component Warm Position Predictions
- Material CTE Measurements

Cold Shifts/Distortions

- REU Photogrammetry
- TRS Photogrammetry
- MS Photogrammetry

Warm Performance

- Feed Roof Range Beam Mapping
- REU Roof Range Main Beam Mapping
- TRS Compact Range Main Beam Mapping

Predict On-orbit Performance using test-correlated models and photogrammetric results

#2 Beam Pointing Knowledge

- Jupiter Boresighting Simulations/Analyses
- ACS Pointing Knowledge Simulations/Analyses/Tests
- STOP Boresighting Drift Analyses
- Timing accuracy analysis/tests (S/C; ACS; Instrument)

#3 Azimuthal Beam Smearing

- Beam Smearing Simulations/Analyses
- ACS Scan Rate Analyses and Tests

MAP

Integration and Verification

Sensitivity: Verification per Sensitivity Error Budget and Specifications

Sensitivity Top-level Error Budget

Tsys Contributors

- Use SS Temp Data (reflectors, feeds, cold DA comps)
- Emissivity Predicts/Msmts (reflector samples & coupons; contam analyses; feeds, sel. cold DA comps)
- Amp Noise Temp Predicts/ Msmts. (NRAO)

Miscellaneous

- # of Channels: by inspection and test
- Integration time: by design
- $\sqrt{2}$ Adjustments by DA tests and mapping simulations
- 10% Data Loss: by analysis and test
- Effective Bandwidth Predicts/ Msmts. (sel. DA comps; DA)

DA Level Verification

- Responsivity: Predicts/Msmts. (gain, phase matching, RF loss (insertion/transmission), band flatness (amps/filters), output voltages to AEU
- Noise Spectral Density (mK-$\sqrt{\text{sec}}$): Predicts/Msmts (incl. broadband amp power noise per PDU spec)
- Evaluate over qual temp range (goal)

AEU & PDU Level Verif.

- Gain: Predicts/Msmts. to achieve Dynamic Range specified (AEU)
- Noise Spectral Density (nv/$\sqrt{\text{Hz}}$): Predicts/Msmts (AEU and PDU)
- Evaluate across qual temp range

MS Level Verification

- Noise Spectral Density Msmts.
- Dynamic Range Msmts.
- Evaluate w/OMT and cold feed loads (T/V-T/B tests w/ Flight Elec. Boxes in T/V-T/B also)

Obs. Level Verification

- Noise Spectral Density Msmts.
- Dynamic Range Msmts.
- Evaluate with cold feed loads (during T/V-T/B tests)

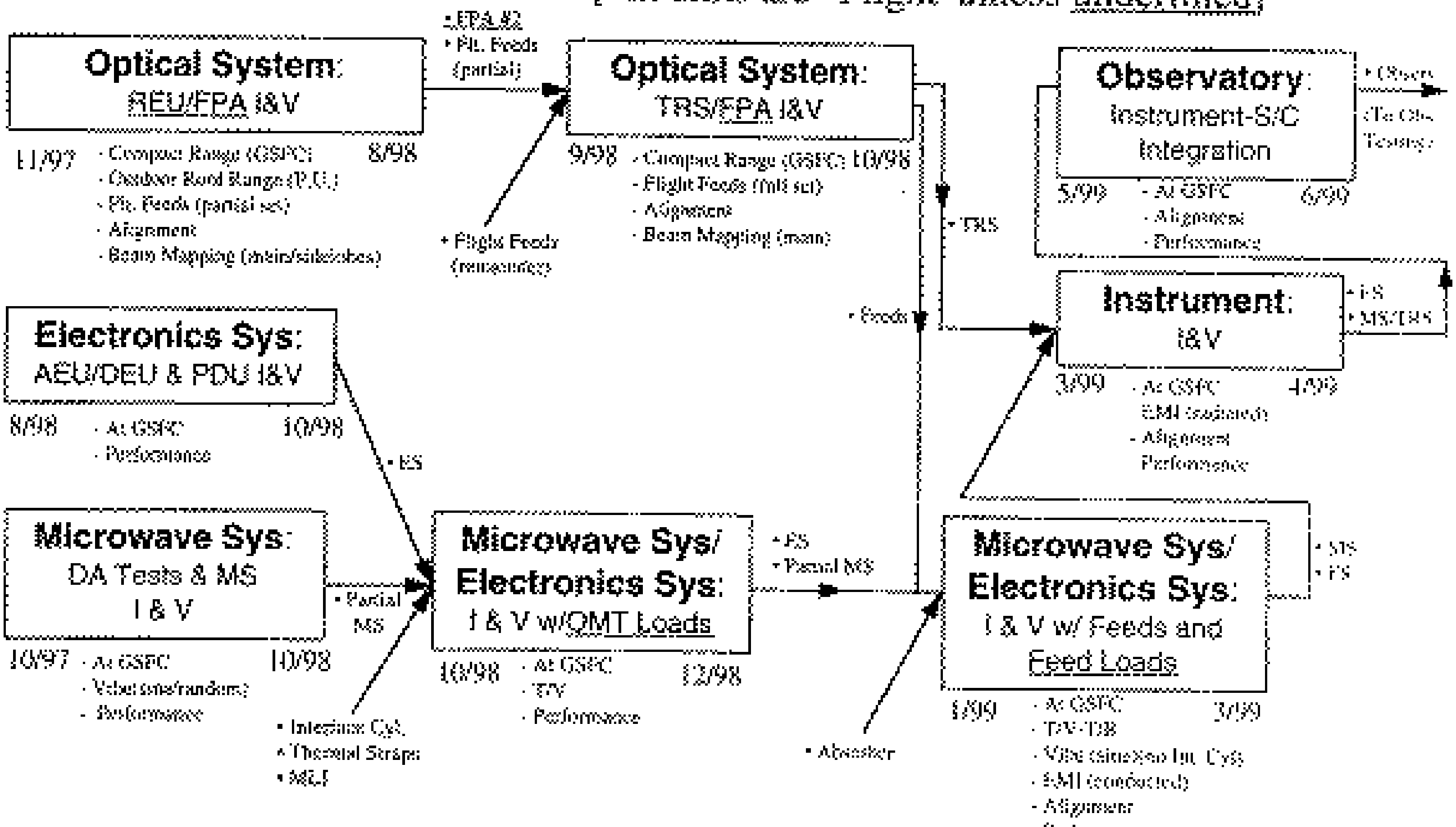
Instrument I&V Flow

MAP

Integration and Verification

Instrument: I&V Flow

[All units are "Flight" unless underlined]



MAP

Integration and Verification

Optical System: REU/FPA I & V (Compact & Roof Range Beam Mapping)

Deliverable Items:

- **TRS Reflector Evaluation Unit (REU)**
- **Flight Feeds**
- **Non-Flight OMTs**
- **FPA Structure #2**
- **Interface Plate (drilled to match the Interf. Cyl. top ring)**
- **S/C and Radiator Diffraction Sim GSE**

Integrate/Align: FPA #2; 90 GHz Feeds; OMTs; 2 GSE Mixers REU	Perform Main Beam Mapping in GSFC Compact Range (Warm)	Ship REU/FPA to Princeton; Integrate w/ S/C and Radiator GSE	Perform Main Beam & Sidelobe Mapping at Princeton (all bands one at a time)	**Disassemble; Deliver: FPA #2 to GSFC Flight Feeds to GSFC**

- Verify YRS Reflector and Feed Designs (main beams and sidelobes)
- Verify STOP models (warm de-focus, 1-G)
- Verify Optical Alignment Techniques (feeds to FPA, and FPA to REU)
- Verify Compact Range performance at 90 GHz

REU Beam Mapping to be performed in GSFC Bldg. 19 Compact Range and at Princeton Outdoor Roof Range

Main Beam Map @ GSFC	Main Beam Map & Sidelobes@ Princeton	Disassemble
Nov 97	Jan 98	Aug 98

Optical System: TRS/FPA I & V (Compact Range Beam Mapping)

Deliverable Items:

- **TRS;**
- **Flight Feeds;**
- **Non-Flight OMTs;**
- **FPA Structure #2;**
- **Interface Plate (drilled to match the Interf. Cyl. top ring)**

Integrate/Align (for full A-side): FPA #2; Flight Feeds; OMTs; GSE Mixers; TRS	Perform A-side Beam Mapping in GSFC Compact Range (Warm)	Remove TRS; Move GSE Mixers to B-side; Re-install TRS	Perform B-side Beam Mapping in Compact Range (Warm)	Disassemble; Deliver: - Thermal/Reflector System to Instrument Integration - Flight Feeds to Microwave System

- Verify Flight Main Beam Size, Pointing, and Polarization (warm de-focus, 1-G)
- Correlate performance with STOP models and extrapolate to predict flight performance.

Beam Mapping to be performed in GSFC Bldg. 19 Compact Range.

Integrate	Main Beam Mapping @GSFC	Disassemble
July 98	Aug 98	Oct 98

MAP

Integration and Verification

Electronics System (ES): AEU/DEU & PDU I & V

Deliverable Items:

- **AEU/DEU**
- **PDU**
- **GSE**
  - *** IGSE w/Procedures**
  - *** Test Harness**
  - *** Copy of S/C Supplied Harness**
  - *** Test Fixture**
- **BTE**
  - *** AEU DA Simulator**
  - *** PDU DA Simulator**
  - *** AEU PRT Simulator**
  - *** S/C Simulator**

[prior to formal electronics delivery]

Leads Integrate Electronics Boxes w/test harness & Subsystem BTE; Test w/BTE Simulators → Integrate Electronics Boxes w/IGSE & S/C Harness Copy; Test w/BTE Simulators → **Deliver ES to Microwave System Integration**

- Verify Interfaces and Performance at BTE & IGSE levels
- Tests done at ambient conditions only
- PDU: Broadband noise to DAs
- AEU: Dynamic Range, Post-demod sensitivity, noise spectral density, temp monitor & RF bias monitor sensitivity

Test with BTE — Aug 98 | Test with IGSE — Sep 98 | Oct 98

Microwave System: GSFC DA Testing and Flight DA/MS I & V

Integration and Verification

Deliverables:

- **DA in shipping container;**
- **MS Structure #4;**
- **Elephant Stand**
- **Flight Instrument Harness for each DA**
- **Flight Absorber**
- **BTE**
  - *** P.U. provides copy of BTE used in final P.U. checkout**
  - *** PRT stim/read**

Post-ship DA Performance Test using OMT loads: Warm in shipping container	Install DA in FPA #1 (vibe fixture) w/ full set of mass models & with Flight Instr. harness	Pre-Vibration Performance Test (OMT loads)	PF/Accept. vibration (All DAs will be vibrated; may shake more than one at a time)	Post Vibration Performance Test (OMT loads)	Instrument DAs with PRTs, per design	**Mount DA(s) w/ Flight Instr. Harness in Flight MS structure; mount RXB absorber**

- Performance Test each DA with BTE and OMT loads (post ship, and pre/post vibration (warm)
- Qual Vibration Test of QTM Prototype Radiometer (7/97)
- Qual Vibration and Cold Test of MS w/mass models and prototype waveguide (12/97)
- PF level vibration of first DA in each band; Acceptance for follow-ons
- Verify/Trend Responsivity, Noise Spectral Density, and Offset

QTM Vibe (MS #1)	MS Qual MS #3	DAs: Post-Ship Test, Pre-Vibe Test, Vibe, Post-Vibe Test, Mount in Flt. MS	
Jun 97	Dec 97	Feb 98 (Post-ship tests start 10/97)	Oct 98

Microwave System/ Electronics System: Integration and Verification

Integration and Verification

Deliverable Items:

- **Electronics System (ES) w/ S/C Harness Copy**
- **MS w/DAs mounted**
- **Flight Thermal Straps**
- **Flt. Interface Cylinder**
- **Flight Feeds**
- **Flight MLI**
- **Flight Absorber**
- **GSE Components**
  - **Elephant Stand**
  - **IGSE**
  - **Cold Feed Loads**
  - **Warm Feed Loads**
  - **Therm. Strap Support**
  - **Interf. Cyl. Simulator**

Integrate ES, S/C Harn. Copy,MLI, and Thermal Straps to MS w/DAs on Elephant Stnd	Perform Ambient Tests w/OMT Loads; Repl. Elephant Stnd w/Interface Cylinder	Perform T/V Tests over Qual Temp Range w/OMT Loads	Remove OMT Loads; repl. Interf. Cyl. w/Sim.; Align Feeds; mount FPA Absorber & closeout the FPA	Perform Vibration Tests (Acceptance Level Sine Sweep); Pre and Post tests w/warm feed loads	Re-install Int. Cyl.; Perform T/V-T/B Tests over Qual Temp Range w/Cold Feed Loads; EMI also.	**Deliver Microwave System and Electronics System to Instrument Integration**

- T/V-T/B Tests done with Thermal Straps sunk to LN2, He Cooled Shroud over the FPA, and Cold Feed Loads sunk to He.
- Performance Test (warm feed loads) done before and after vibration
- Verify Thermal and Structural Design and Analysis Results
- Confirm Princeton DA and GSFC Electronics Performance Results over Operational Temperature Range (Qual Range Goal)
- EMI testing (conducted susc. & emiss.) performed during T/B test
- Verify/Trend Responsivity/Gain, Noise Spectral Density, Dynamic Range, & Offset

Integrate	T/V w/ OMT Loads	Install Feeds	Vibrate	w/Feed Loads	
Oct 98	Nov 98	Jan 99	Feb 99	Feb 99	Mar 99

MAP Cold Feed Load Requirements

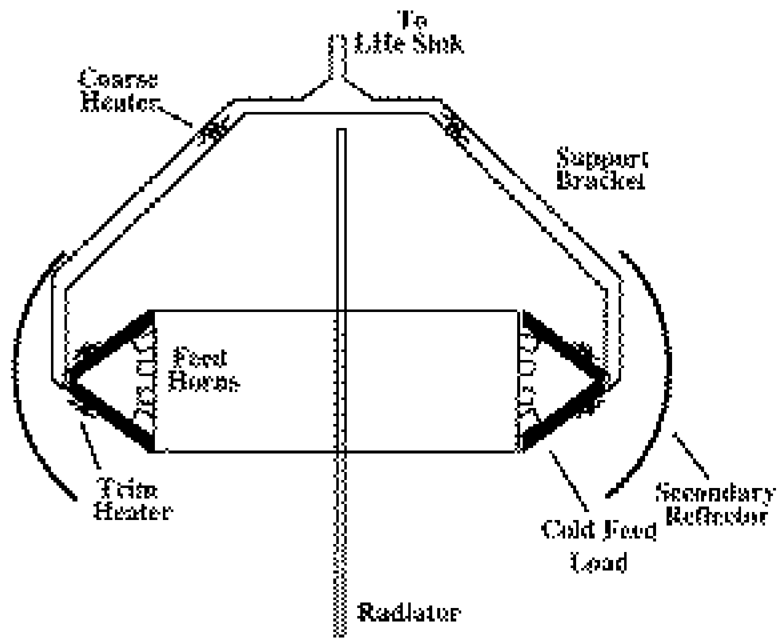
Integration and Verification

Goals	Cold Feed Load Requirements
- Insensitive to environment →	• Fill beam: Leakage < -40 dB
- Insensitive to Position →	• Reflection < -40 dB
- Temperature ≠ Receiver →	• Cold Loads (T < 30 K)
- Bring output on-scale →	• Coarse balance within 10 K
- Measure gain & offset →	• Fine balance within 0.1 K
- Measure 1/f noise →	• Temperature stable to 100 µK/min

Cold Feed Load Concept

MAP Integration and Verification

- Microwave absorber tilted near Brewster angle;
- Balanced semi-passive design(slow feedback loop for fine control);
- Separate heaters for coarse & fine thermal control;
- Absorber buffered to reduce thermal gradients & drifts;
- Load support bracket will be cantilevered out to support the loads above the TRS, and then will be lowered to position the loads between the secondaries and the feeds.
- Same cold feed load will be used for all vacuum testing of the MS with feeds
- Cold feed load will fit beneath the LHe shroud



Observatory: Instrument Testing at the Observatory Level

Integration and Verification

- Perform Warm Feed Load tests during Comprehensive Performance Test (CPT) to provide trending data; perform EMI testing (radiated susceptibility/emissions) at the Observatory Level, and evaluate results against the trend data.

- Perform limited function tests during Aliveness tests (no loads used);

- During T/V-TB testing, repeat the detailed performance tests per the Microwave System T/V-T/B tests. This will be done with the Cold Feed Loads in place, and the data acquired during these tests (particularly the 192 hour Thermal Balance soak) will provide definitive data on the noise spectral density of the instrument and the sensitivity of its response to temperature fluctuations.

- Near the end of the Thermal Balance testing would be an ideal time to vary the power on the bus at the spin-rate to look for an instrument response.

Instrument: Integration and Verification

Deliverable Items:

- **Thermal Reflector System**
- **Microwave System w/ Electronics System (S/C Harness copy)**
- **Integration Procedures**
- **GSE**
  - **IGSE**
  - **Elephant Stand**
  - **Warm Feed Loads**

Align TRS to MS; Pin and Mount; Attach Thermal Straps to Radiators	Perform Radiated Emissions/ Susceptibility Tests in EMI Facility: Verify w/ Performance Tests w/warm feed loads	Warm Performance Tests (Observatory Baseline Tests) w/ Warm Feed Loads	**Deliver the Instrument to the Observatory**

- Verify/Trend responsivity, noise spectral density, dynamic range, and offset
- It would be possible to skip the TRS/MS alignment at the Instrument level, and deliver the TRS and MS to the S/C for integration following MS EMI testing and warm performance tests.

Integrate	Tests	Deliver
Mar 99	Apr 99	Apr 99

MAP Integration and Verification

Observatory: Integration of the Instrument and S/C

Install Electronics Boxes on S/C and Integrate Mechanically and Electrically	Align Interface Cylinder to S/C interface; pin and mount	Remove TRS from MS; Mount MS on Elephant Stand Above Int. Cylinder	Integrate S/C Harness to ES and MS, and Performance Test Instrument w/ Warm Feed Loads	Remove Elephant Stand; Align MS to Interface Cylinder; pin and mount; Tie down service loops	Align TRS to Interface Cylinder; pin and mount; Attach Thermal Straps to Radiator; mount Omni	Perform Performance Tests w/ Warm Feed Loads (Baseline)

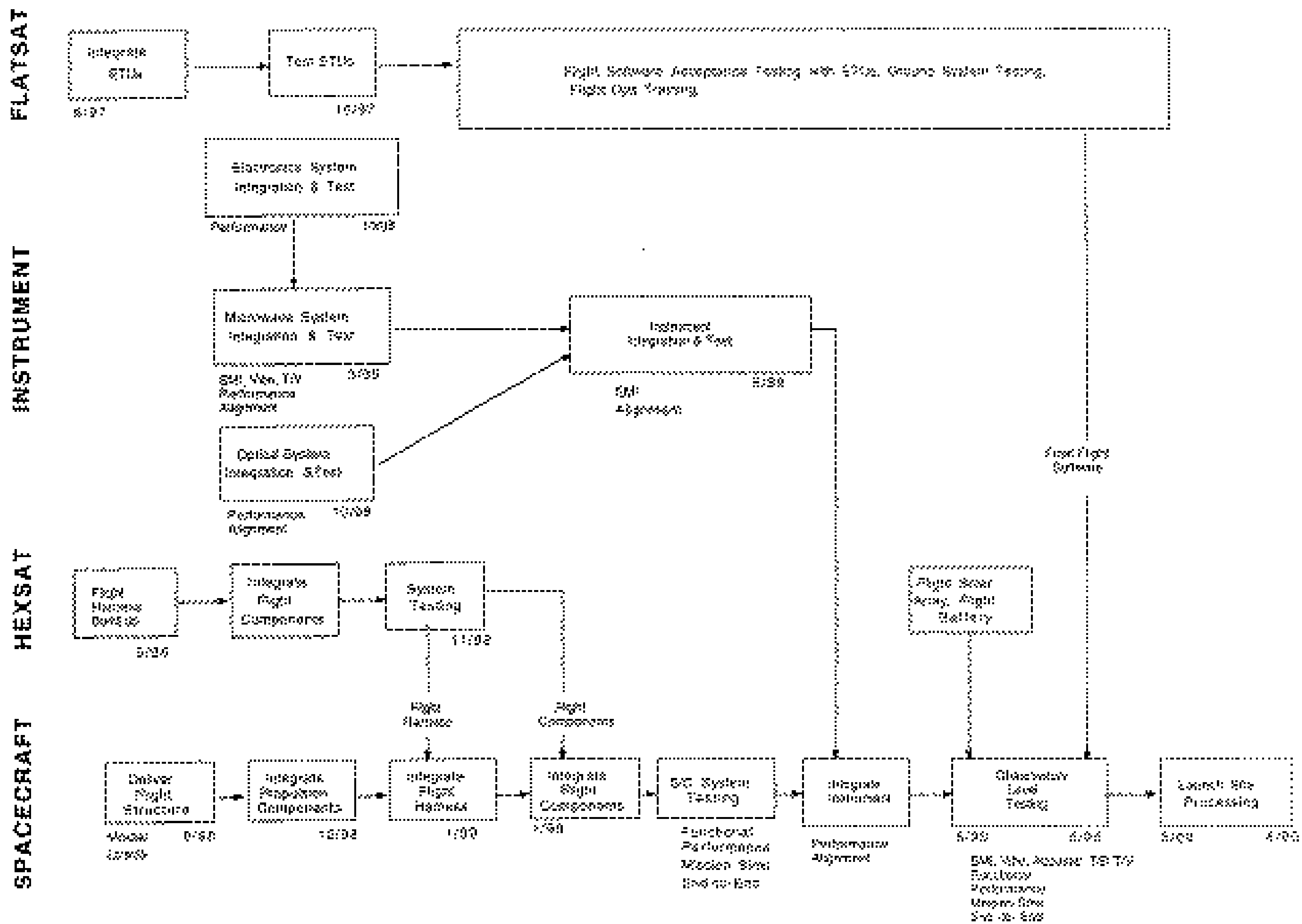
- Elephant Stand provides access to RXB during initial performance testing; ≤ 24" service loops eliminate need to break any harness connections after performance is confirmed.

- Verify/Trend performance (dynamic range, responsivity, offset, noise spectral density) and establish baseline values for warm CPTs.

Integrate — Tests

May 99 — May 99 — Jun 99

MAP System Integrat. & Verification Flow



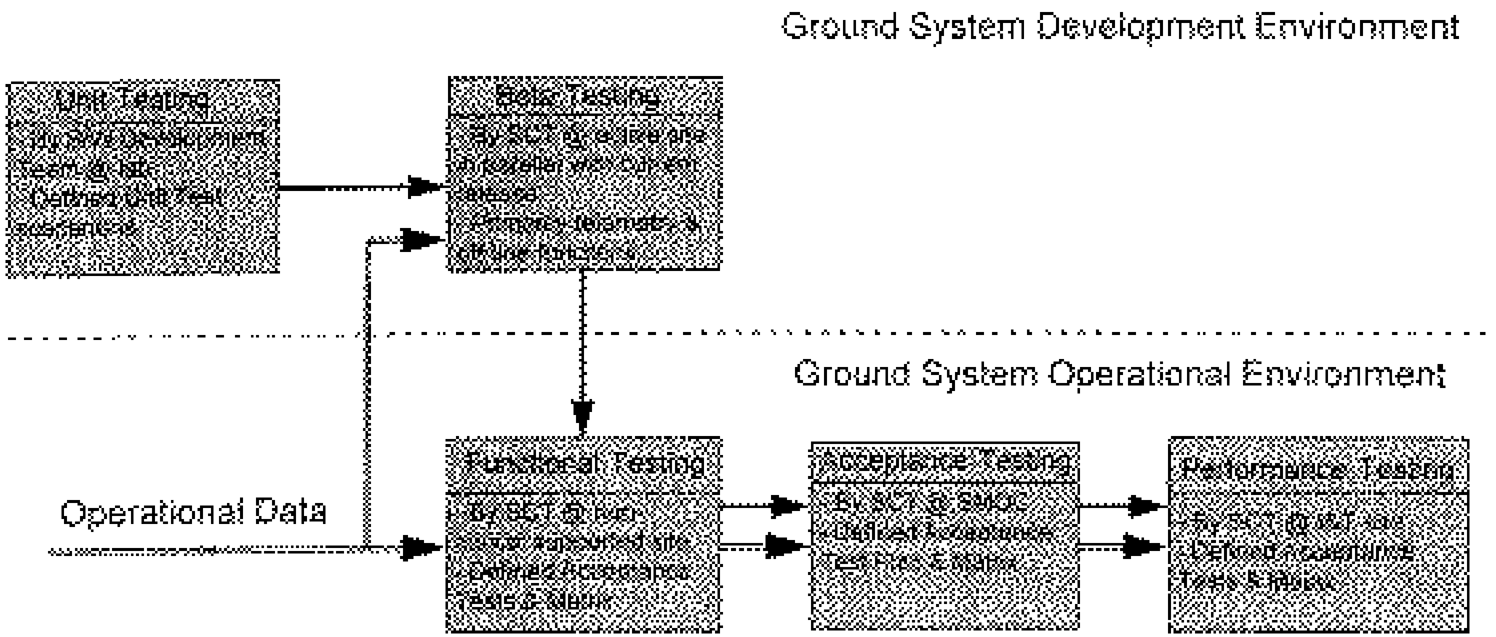
— Verification

Ground System Test Approach

- Ground System Release Tests
  - Development Team unit tests prior to release
  - Beta Releases are informally evaluated by the SCT prior to release
  - Released version is evaluated by the SCT prior to wide distribution
    - Tested at non-critical site (i.e. Flatsat)
    - Test Plans are operationally oriented
    - Plans are authored and executed by the SCT
  - Full distribution coordinated with each site
  - Requires End-to-End Tests & Mission Simulations to fully verify functionality & performance

Ground System Test Flow

Verification



MAP

Verification

Observatory Test Approach

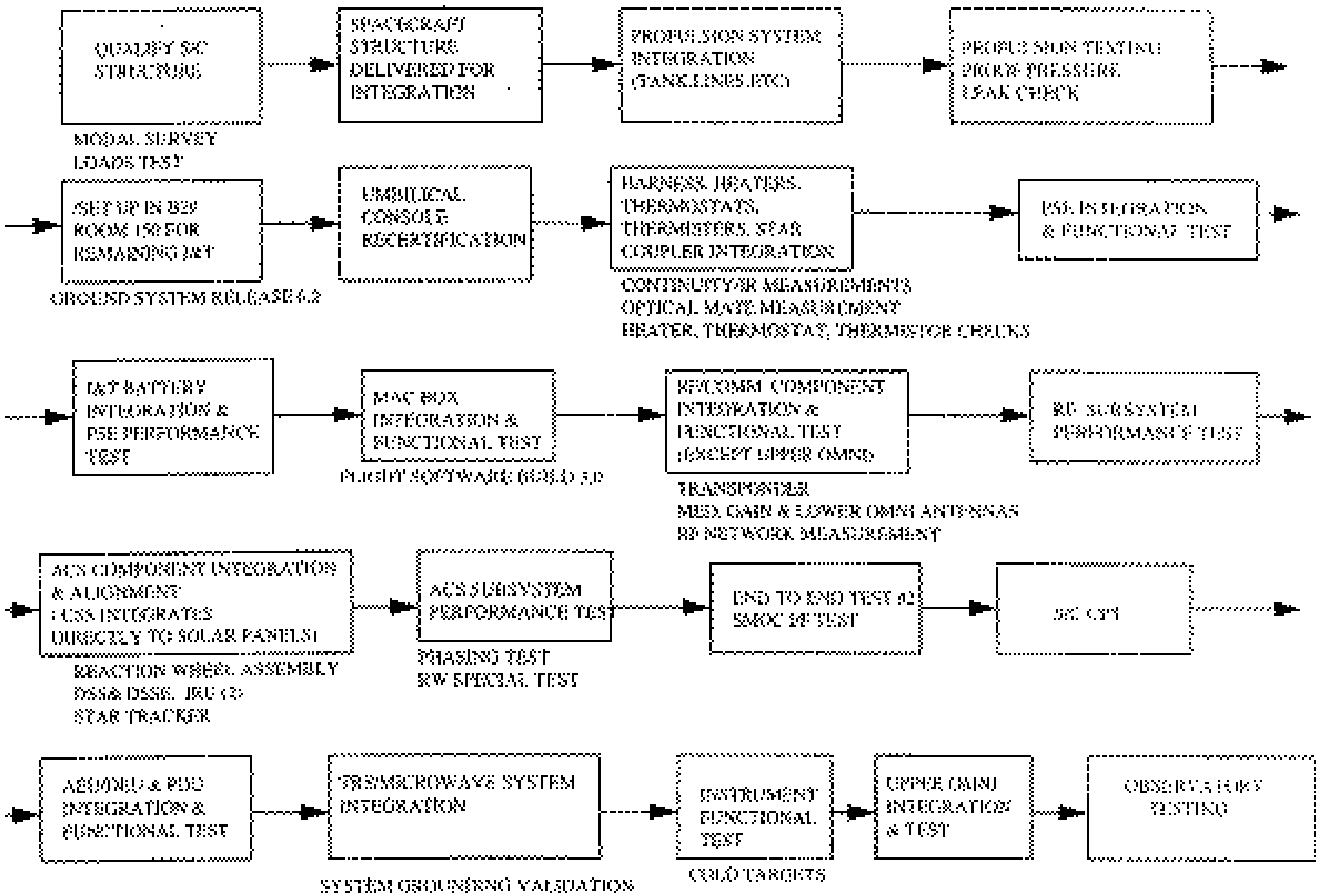
- On orbit resources support MAP from component development
  - -- Combined Ground System (CGS)
  - -- Spacecraft Controller Team (SCT)
  - -- Spacecraft Development Team (SDT)
  - -- Documentation, databases and STOL procedures
- All elements are tested as they will be flown
- Modular STOL procedures developed from component test
- STOL procedures support system testing and operations
- Verification matrix maintained from component level

MAP
Verification

Flight Software
Verification Approach (4 Phases)

- **Unit Testing**
  - Performed using PC-based Simulation tools by Software Developer
    - RSN - UTMC69R000 PC Simulator
    - Mongoose - Windows 95 Visual C++ Software Bus Simulator
- **Integration Testing**
  - Performed on breadboard hardware in the software development lab by the Software Developer. Build Testers assist the developer in the verification of all GSE interfaces.
- **Build Testing**
  - Performed by Build Test Team at the end of each software release
  - Where possible build tests will be re-used from XTE/TRMM testing effort
- **Acceptance Testing**
  - Performed by Build Test Team at the MAP ETU Lab.
  - Build test team will take selected build tests and various mission scenarios in order to develop a series of acceptance tests
  - MAP Systems will assist in the development of acceptance tests
  - Acceptance Test Plan will be independently reviewed.

Spacecraft I&T



Test Descriptions

Aliveness, Functional & Performance Tests

Verification

- Aliveness Test
  - Origin - Integration Procedure
  - Tests power on/off, CMD/TLM and connectivity to all I/F
  - Short duration, little GSE support

- Functional Test
  - Standalone test of basic functionality against GO / NOGO criteria
  - Evaluates all planned operational modes, data collection & verification of I/F
  - < 1 shift & may require GSE support

- Performance Test
  - Assess against verification matrix & modeled after mission sequences
  - Verify functional requirements & thoroughly evaluates observatory level I/F
  - Primary verification of mission readiness
  - > 1 day & GSE generally required and excellent trend reference data source

Verification

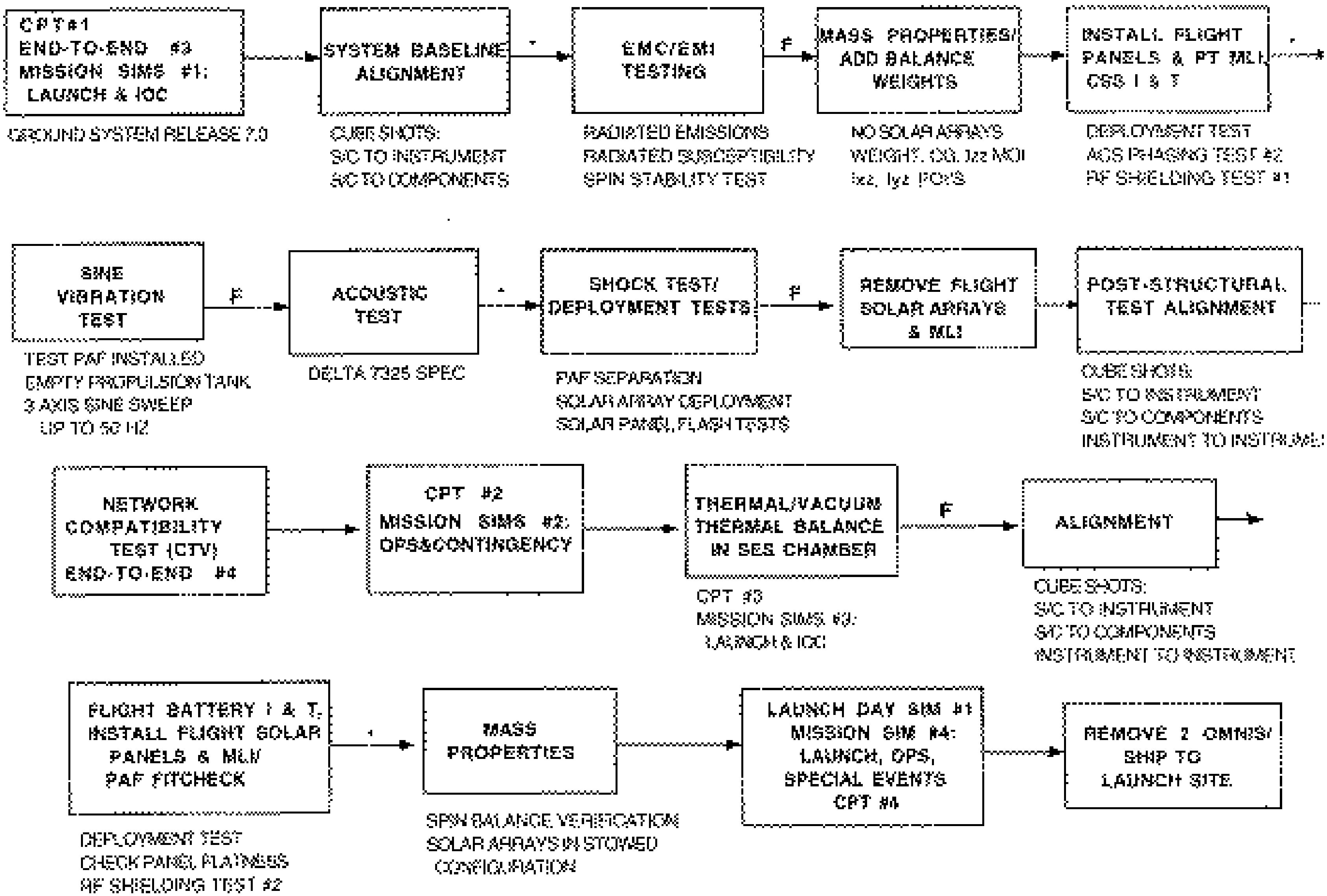
Test Descriptions

End - to - End & Mission Simulations

- End-to-End Test
  - Tests all planned ground interface configurations
  - Verifies Ground & Space Segment I/F functionality
  - Tests specific interfaces:
    - SN, DSN, NASCOM, CTV, CTT, KSC, SMOC, MTOC
  - Usually one day in duration

- Mission Simulation
  - Utilizes all On-Orbit resources
  - Specific realistic simulations
    - Launch - In-Orbit Checkout (IOC)
    - Mission Operations (OPS) - Contingency
    - Special Operations
  - Verifies performance of Ground & Space systems and their I/F
  - Verifies On Orbit procedures and SCT performance
  - > 1 day & may require GSE support

MAP OBSERV ORY LEVEL TESTING



* = ALIVENESS TESTS PERFORMED   F = FUNCTIONAL TEST PERFORMED

EMI Test Summary

Verification

- Box Level
  - Conducted and radiated susceptibility & emissions
    - Reaction Wheel & Electronics (1 RWA)
    - Inertial Reference Unit (1)
    - Digital Sun Sensor & Electronics
    - Star Tracker
    - Instrument AEU/DEU and PDU
    - PSE
    - MAC
    - Transponder
- Instrument Level
  - Radiated emissions & susceptibility
    - Conducted susceptibility test performed without TRS
- Observatory Level
  - Radiated emissions & susceptibility
    - RS levels include Delta C band transmitter
  - Spin stability test, simulates bus voltage

EMI/EMC Test Levels

Description	Test Level	Comments
Conducted Emissions		
CE01/03, NB	120 to 20 dbuA	
CE01/03, BB	125 to 50 dBuA/MHz	
Conducted Susceptibility		
CS01	2.8VRMS/40 Watts	500mV for first CS test
CS02	1.0 VRMS/1 Watt	500mV for first CS test
CS06	28V+/- 28V, 10usec Pulse	n/a for first EMI/EMC test
Radiated Emissions		
RE02, NE	20 to 65 dBuV/m	
RE02, BB	55 to 95 dBuV/m/MHz	
Radiated Susceptibility		
RS03,14 KHz-2GHz	2 Volts/m	
RS03,2 -12GHz	5 Volts/m	
RS03, ~2287.5 MHz	40 Volts/m	
RS03, 5.762 - 5.788 GHz	40 Volts/m **	Inst Off Survival Test
RS03, 12 - 40 GHz	1Volt/m	ICD with Launch Site
Common Mode Noise Emissions		
Power Lines	100 mVpp (50 mVpp Goal)	
Signal Ground	100 mVpp (50 mVpp Goal)	
Spin Period Stability Test		
Emission, 0.0003 to 50 Hz	500 mVpp	
Susceptibility, 0.0003 to 50 Hz	500 mVpp	

Verification

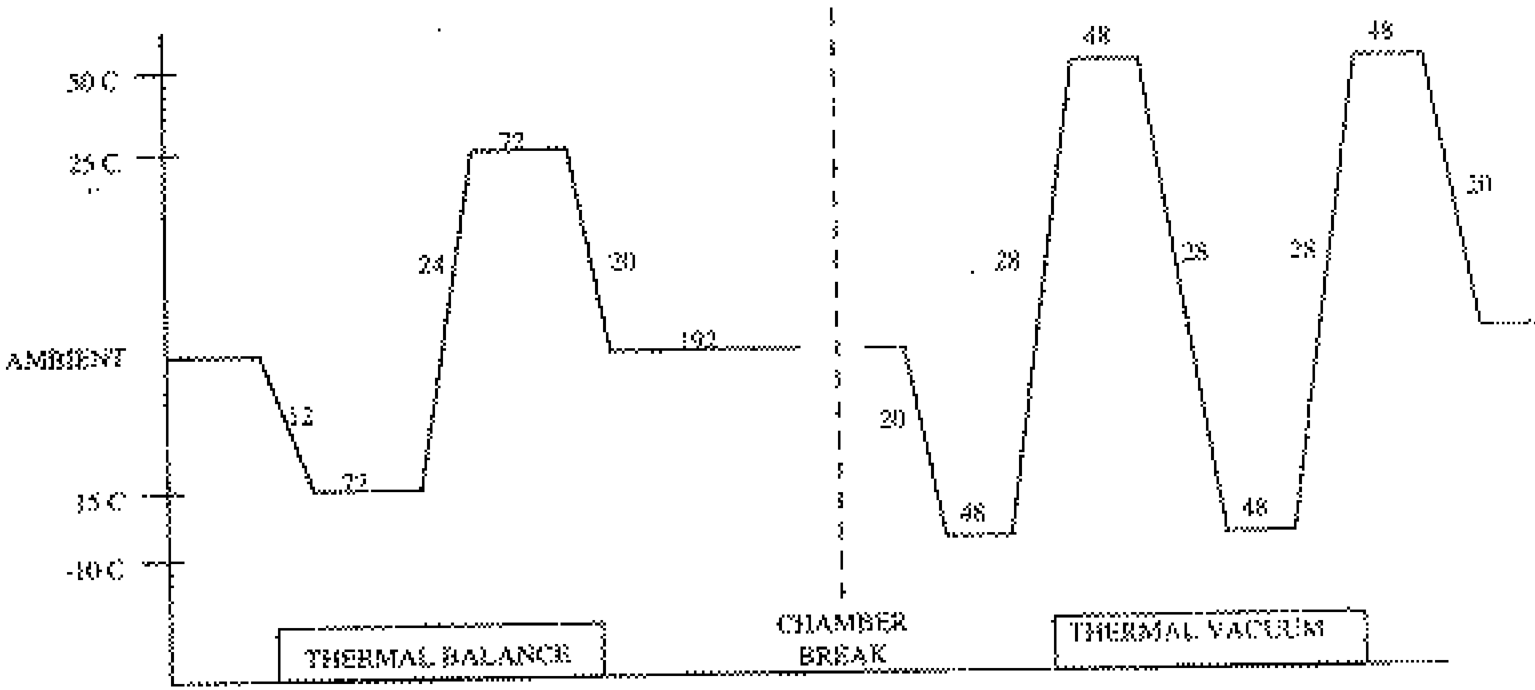
Structural Test Summary

- Box Level
  - Strength, random & sine vibration testing
    - Reaction Wheel & Electronics (3 RWA's)
    - Inertial Reference Unit (2)
    - Digital Sun Sensor & Electronics
    - Coarse Sun Sensor
    - Instrument AEU/DEU and PDU
    - Transponder
    - Solar Panels (& acoustics)
    - Omni (2) and Medium Gain Antennas
    - Propulsion Tank, Thrusters, Valves, Transducers, Filters
    - Instrument AEU/DEU and PDU
    - PSE
    - MAC
    - Transponder
    - Star Tracker
    - Battery
    - Diplexer
    - SA mechanisms
    - Star Couplers
- Instrument Level
  - Testing performed on the TRS & Microwave S/S
- Observatory Level
  - Sine sweep test (up to 50 Hz), acoustics, shock

Thermal Test Summary

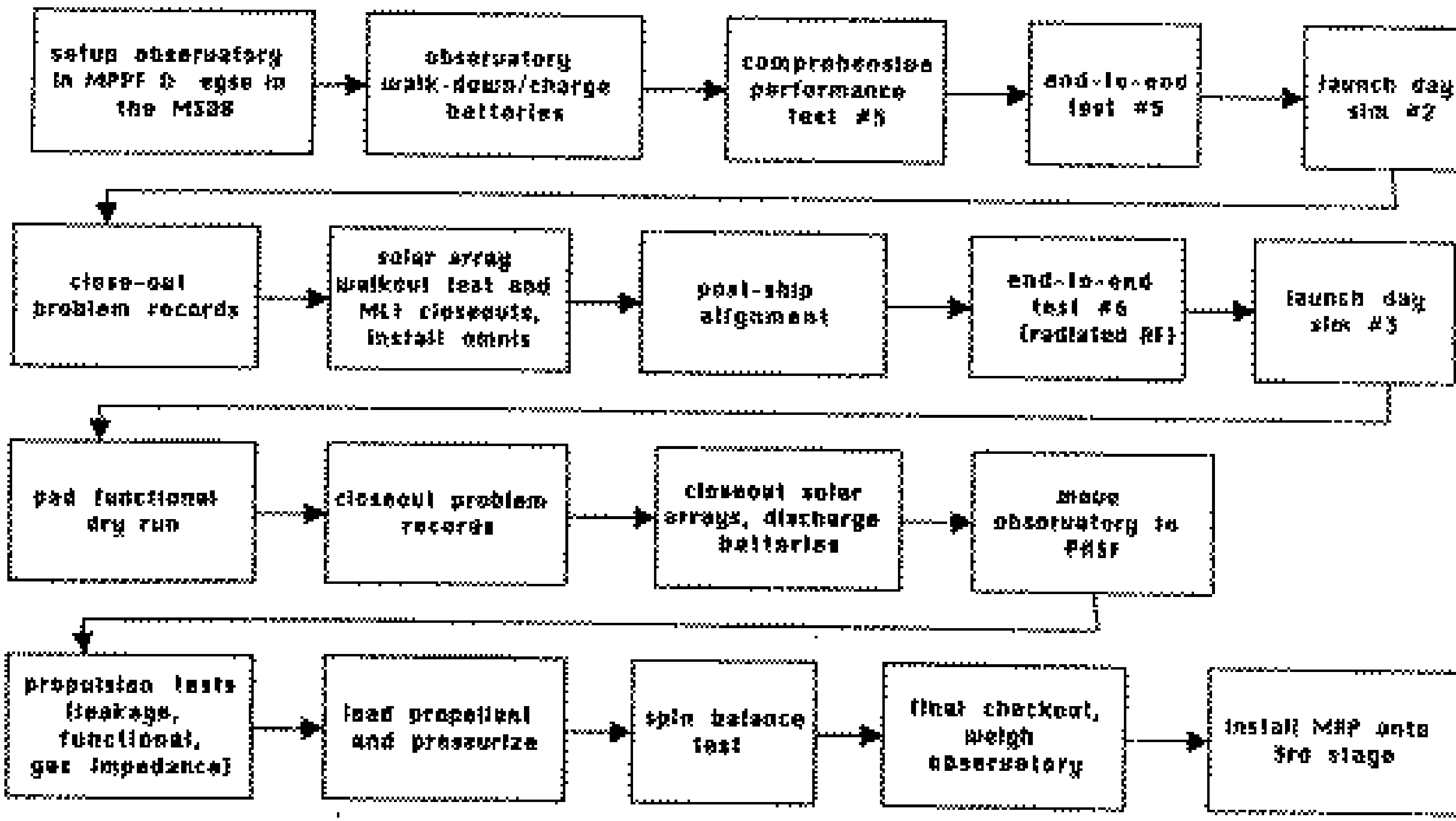
- Box Level
  - 8 thermal cycles, +/- 10 degrees qual and +/- 5 degrees acceptance
    - Reaction Wheel & Electronics (3 RWA's)
    - Inertial Reference Unit (2)
    - Digital Sun Sensor & Electronics
    - Coarse Sun Sensor
    - Instrument AEU/DEU and PDU
    - Transponder
    - Solar Panels
    - Omni (2) and Medium Gain Antennas
    - Instrument AEU/DEU and PDU
    - PSE
    - MAC
    - Transponder
    - Star Tracker
    - Battery
    - Diplexer
    - SA mechanisms
    - Star Couplers
- Instrument Level
  - Testing performed on Microwave & electronics (4 cycles) with Helium shroud
  - TRS testing with photogrammetry, radiater interface heat load verified
- Observatory Level
  - T/V (2 cycles, qual temperatures as a goal) and T/B (worst case hot & cold)

PRELIMINARY MAP OBSERVATORY THERMAL BALANCE/ THERMAL VACUUM TEST PROFILE (SES FACILITY)



- SOAK DURATIONS IN HOURS (T/B IS 17 DAYS, T/V IS 13 DAYS)
- INSTRUMENT WILL BE IN A HELIUM SHROUD THROUGHOUT T/B AND T/V TEST
- GOAL IS TO GET 2 WEEKS RUN TIME ON THE INSTRUMENT
- MAP SYSTEM LEVEL TESTS INCLUDE:
  CPT, FUNCTIONALS, ALIVENESS, MISSION SIMS, LAUNCH SIM, SAFEHOLD, S/S SPECIAL TESTS
  COLD& HOT START, BAKEOUT

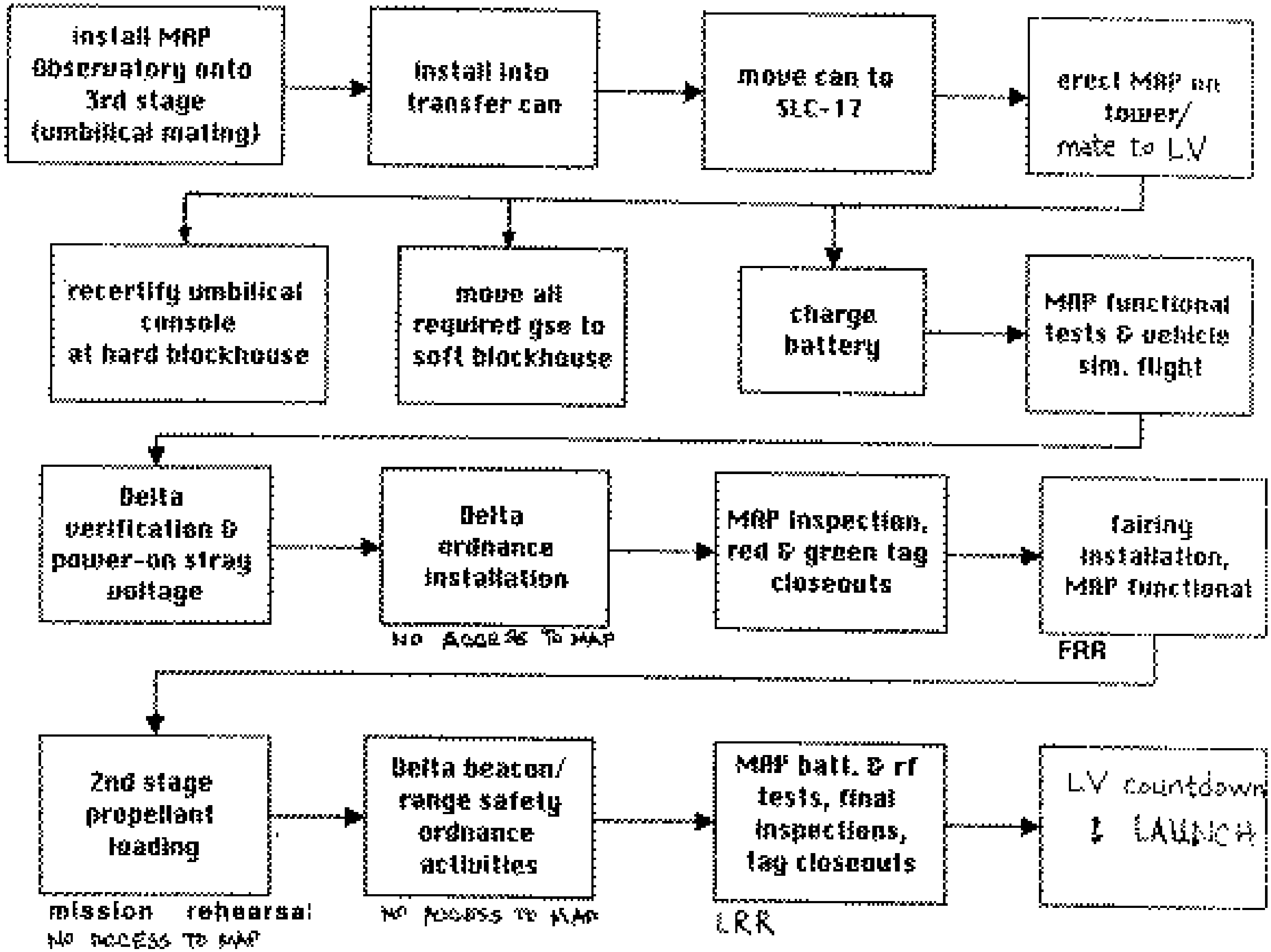
MAP Launch Site Activities



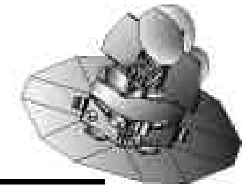
* MAP baselined to arrive by CSA

1/15/97

MAP/Delta Activities

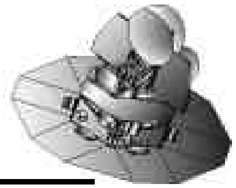


Reliability



- Reliability Philosophy
- Failure Modes and Effects Analysis
- Process for Risk Indentification and Mitigation
- Redundancy/Operational Workarounds and Graceful degradation

Reliability Process Overview



- Reliability is designed in from the beginning
- FMEA to identify mission threatening failures from mission degradation
- Reliability failure rate analysis used to weigh the benefit of one design implementation versus another
- Revise designs to convert loss of mission failures into loss of function or mission degradation
- Inspection to verify as built hardware meets designer’s intent
- Testing to verify as built hardware meets designer’s requirements
- Onboard Fault Detection and Correction to safe spacecaft to provide ground time to react and potentially recover from anomaly
- Operational Contingency Procedures and Backup Plans for mission critical and recoverable failures
- Reliability Philosophy communicated to MAP Hardware Suppliers

Analysis Philosophy

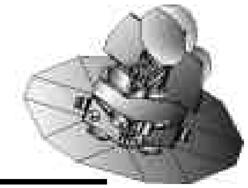
- Reliability and Failure Modes and Effects Analysis have different goals for redundant and single string spacecraft.
- As a single string spacecraft MAP strives to minimize the effects of a failure whereas a redundant spacecraft strives to avoid single point failures.
- A large number of faults can result in mission loss. However, there are also many failures that may result in partial loss of function or in a reduction in performance. These type of failures result in “graceful degradation”.
- A redundant spacecraft design focuses primarily on preventing single point failures and focuses less on designing in graceful degradation.
- For MAP designing in graceful degradation is much more important since there are minimal redundant units available for backup.
- MAP manufacturing process control and inspection are as important as they are on a redundant spacecraft. Manufacturing process control may even be more important because there is only one chance to get it right.

Reliability Process

Design and Analysis Phase

1. Perform System Level FMEA to determine failures that result in mission loss versus mission degradation
2. Adjust design or implementation such that failures categorized as mission loss are moved to the degraded mission category. The overall goal is to reduce the number of potential mission failures.
3. Reliability failure rate analysis is used to weigh the relative benefit of one design implementation versus another.
4. Where failures result in graceful degradation and require rapid ground intervention or changes in operational plans to save the spacecraft, prepare contingency procedures or software loads to implement them.
5. Critically review the design of the spacecraft power bus. A short on the primary power bus can take out the whole spacecraft. The design of the power bus is such that shorts are considered not credible by design.
6. Peer Review process for both Hardware and Software to identify potential design and/or implementation problems.

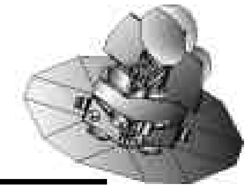
Reliability Process



Manufacturing and Inspection Phase

1. Failures are viewed as mechanical. Whenever an item fails it usually means that something moved, whether internal to a chip, on a circuit card or in harness. If it worked once and then does not, something moved.
2. Stress relief against vibration, mechanical motion, and thermal expansion.
3. Clearance to protect against shorts. Close inspection as lower level sub assemblies are assembled.
4. The power system electronics are carefully inspected during assembly to screen for potential shorts. Shorts on the power bus are considered not credible following inspection.
5. Eliminate sources and provide barrirers to Contamination that could cause shorts or degrade the surface properties of instruments or thermal control surfaces

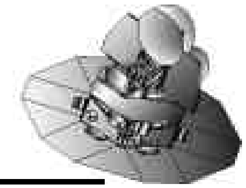
Reliability Process



Test Phase

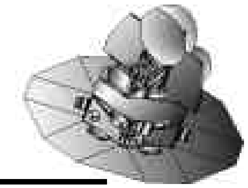
1. Test and or execute the sequences planned for the mission. Perform steps and send commands in the expected sequence with the expected timing
2. Command sequences are verified prior to first time execution onorbit. If a sequence is performed onorbit for the first time, analysis should exist that indicates the item will work. Items are tested in “pieces or in steps” instead of relying on analysis alone.
3. Critically test flight and ground software against requirements and the intended end item function.
4. Exercise the hardware and software together during environmental test in the modes they are operated during the mission.

Reliability Process



Operations Phase

1. Utilize a simple subset of the total Spacecraft electronics suite to provide an ACS Safehold that allows additional time for the ground to recover from an anomaly
2. Onboard failure detection to minimize the impact of mission threatening anomalies
3. Contingency procedures prepared for critical subsystems and mission events
4. Training and exercising of the flight and ground systems during prelaunch mission simulations

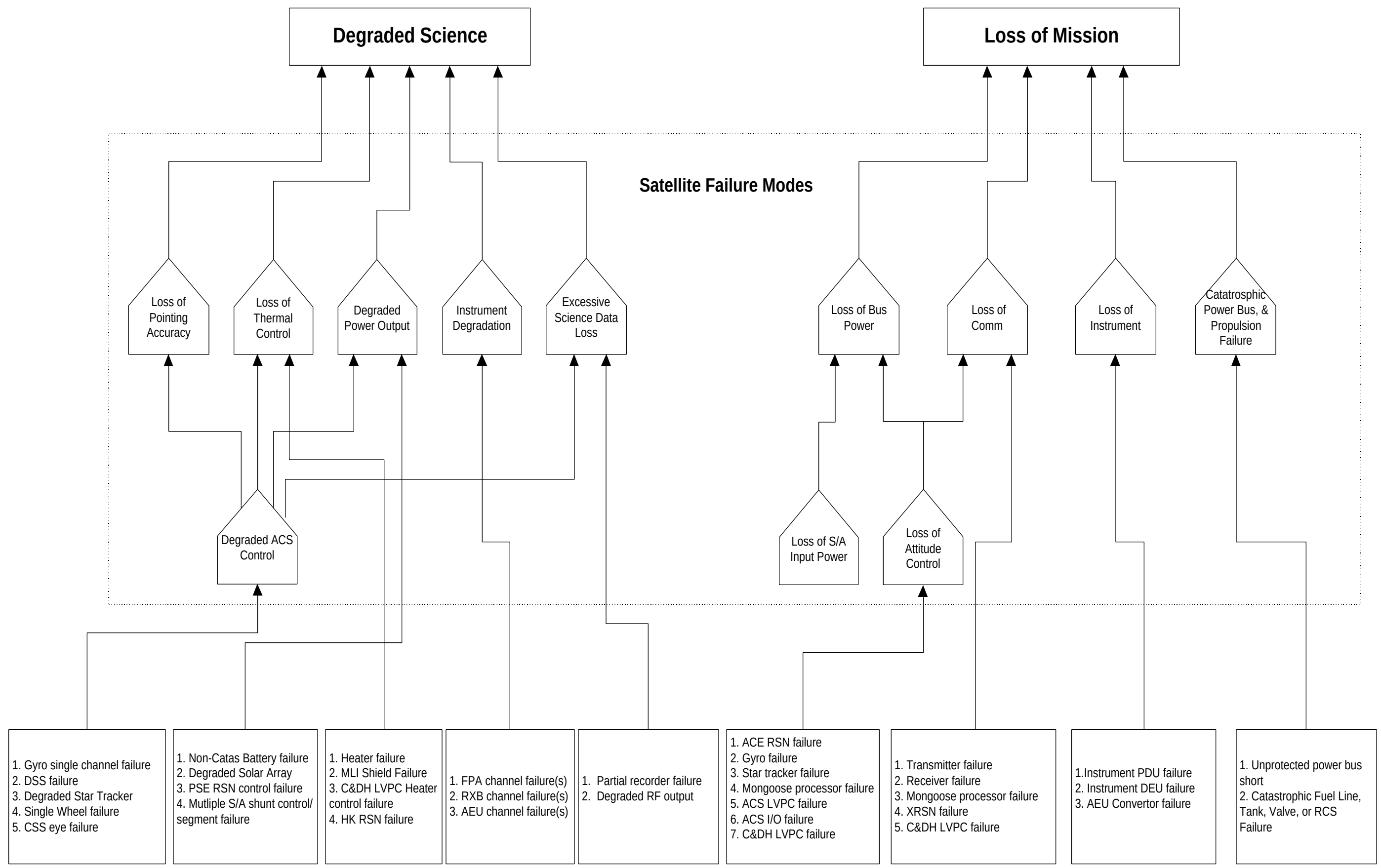


Status

- Interface level FMEA Complete (PDR Design)
- Identified / implemented design changes
- Mitigation approaches (analysis, inspection, test) developed for high risk (high probability and severe consequence) failures that can not be mitigated by hardware design changes
- Critical items list and associated controls generated
- Update to interface level FMEA performed concurrently with piece part level electrical circuit review (CDR Design)

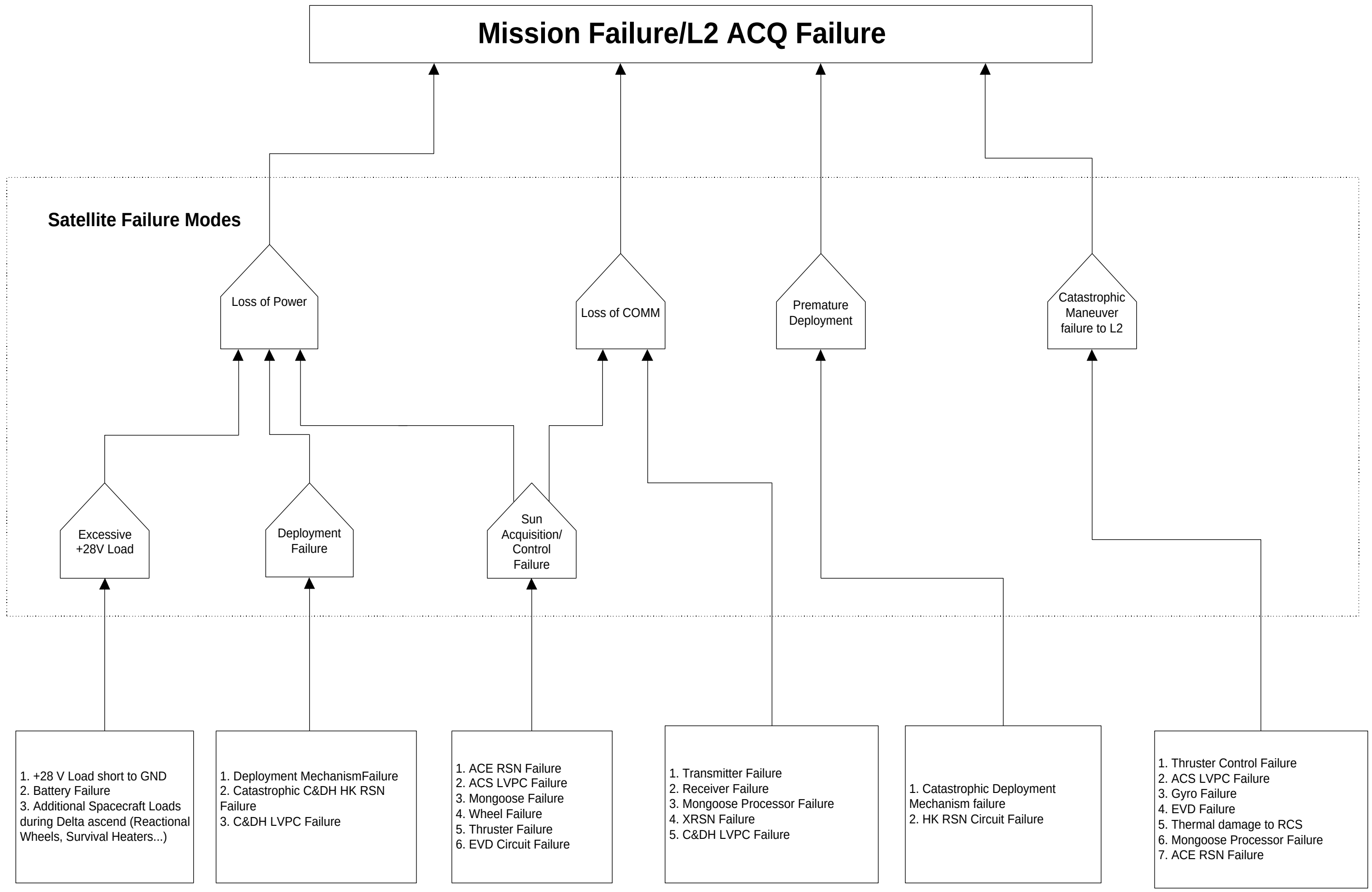
Mission Fault Tree

MAP Mission Level Fault Tree/Reliablity Assessment (Mission Mode)

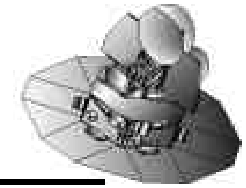


Mission Fault Tree

MAP Mission Level Fault Tree/FMEA (Launch/L2 Orbit Maneuver Mode)

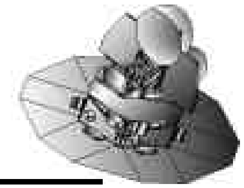


Graceful Degradation



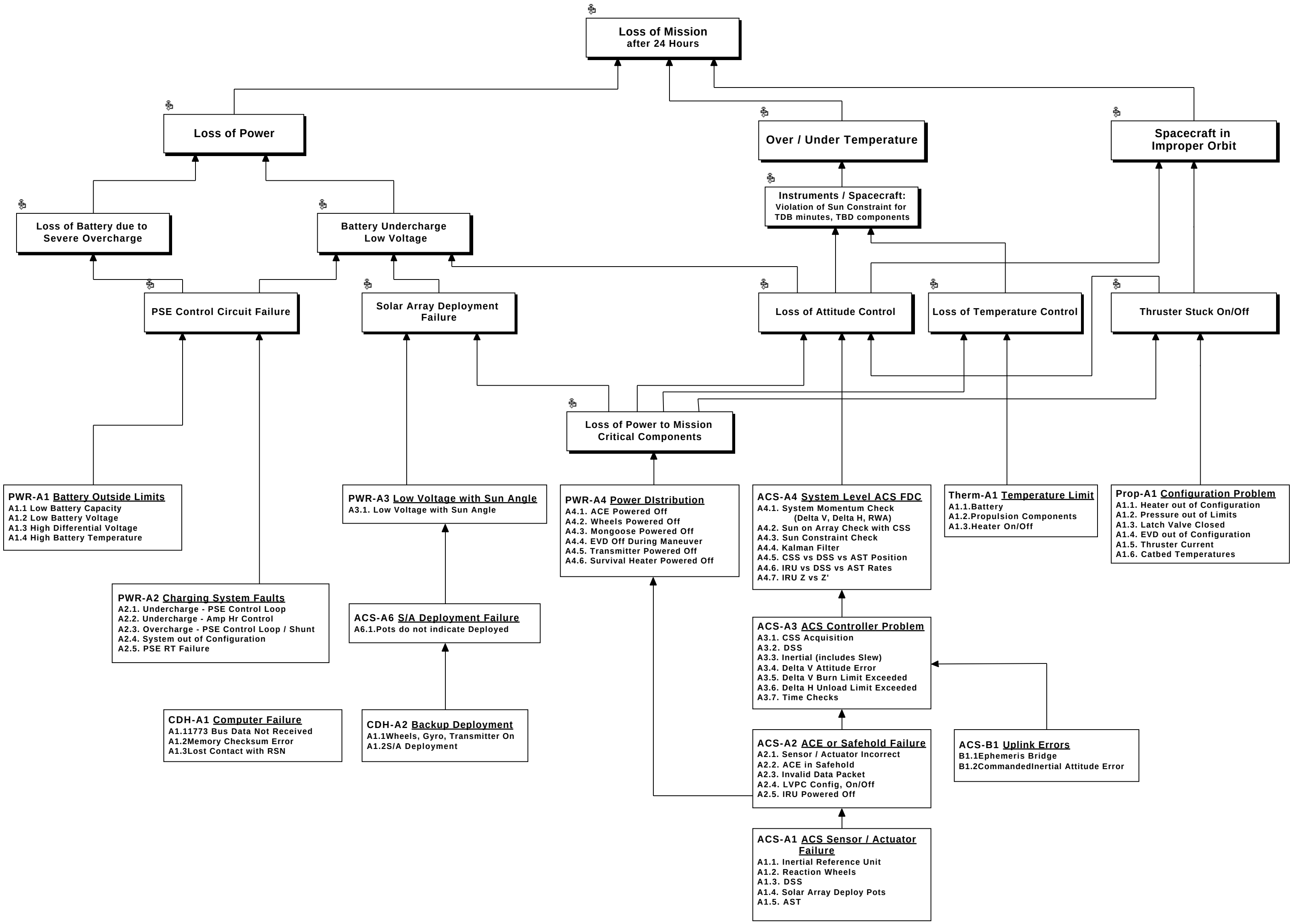
- Selected Redundancy
  - •Deployment Actuators, Deployment Hinge Bearings & Springs
  - •Gyro Z axis
  - •1773 Bus and couplers
  - •Selected Power Distribution and current shunt wiring
  - •Selected Survial Heaters for Operational Heaters
  - •Transponder (under consideration)
- Operational Workarounds and Graceful degradation

Prime Item	Mitigator
•Hardware/Software	Safehold (Simple algorithm, reduced ACS hardware set)
•Processor	Special Commands to Reset
•Wheels	Thrusters
•Thrusters	Transfer momentum with wheels to axis with working thrusters
•Gyros	Star Tracker Derived Rates (under consideration)
•Star Tracker	DSS and Ground Based Attitude Estimates
•PSE Algorithms	Hardware voltage limit/control
•Instrument	Multiple channels



Onboard Health & Safety Monitoring

Reliability



Safety & Mission Assurance

Safety and Mission Assurance (S & MA)

Mike Delmont, Mike Jones, Tim Bowser, Antonio Reyes, Tim Van Sant, and Mike Hill

- Quality Assurance
- Parts
- Materials
- System Safety
- Conclusion

MAP S & MA Requirements/Guidelines

Safety & Mission Assurance

- No Mission Classification.
- Brief MAR (MIDEX Assurance Requirements) document provides fundamental S & MA requirements for Medium Class Explorers.
- Emphasis on ISO 9001 approach to use existing processes, plans, procedures, work instructions.
- Invokes Hi-Rel Workmanship Standards.
- Defines requirements for Safety, EEE Parts, Materials, System Reviews, Verification, and Reliability.
- ISO 9001 approach Allows Princeton/GSFC/Supplier Team Flexibility with respect to choosing their path to Compliance.

Quality Elements

Safety & Mission Assurance

MAP Project addresses each of the twenty elements defined in ISO 9001.

4.1 Management Responsibility: Defines management responsibility for establishment and implementation of the MAP Quality System.

4.2 Quality System: Implements the ISO 9001 concept and MAP Project requirements.

4.3 Contract Review: Deals with examining and reviewing contract requirements to ensure they are adequately defined and documented.

4.4 Design Control: Explains the review process and methods to control, verify, and validate the design of flight hardware and software elements and the critical ground support equipment.

4.5 Document and Data Control: Establishes the requirements of formal MAP Configuration Management System.

Quality Elements

4.6 Purchasing: Identifies the responsible individuals and defines the procedures to be followed for the procurement of flight hardware and software.

4.7 Control of Customer Supplied Product: Ensures that Government Furnished Equipment (GFE) and data for MAP project are protected against loss and deterioration.

4.8 Product Identification and Traceability: Describes certification log as a method for identifying a product from receipt of material through product installation and delivery.

4.9 Process Control: Identifies the workmanship standards and requirements for control of processes used for fabrication, assembly, integration, test, and handling of flight hardware.

4.10 Inspection and Testing: A closed loop system for control of all procured parts, materials, and services and to ensure that inspections and tests have been performed to verify compliance with all contract specification and drawing requirements.

Quality Elements

4.15 Handling, Storage, Packaging, and Delivery: Provides for the safe handling, storage, and packaging of MAP products from receipt through delivery.

4.16 Quality Records: Provides direction on proper storage and control of inspection reports, procedures, inspection/test documentation, and other supporting information.

4.17 Internal Quality Audits: Establishes Quality procedures to be implemented and followed to determine the effectiveness of the procedures in controlling the quality of MAP products.

4.18 Training: Identifies training needs for personnel performing activities that affect the quality of the MAP Spacecraft.

4.19 Servicing: Not Applicable.

4.20 Statistical Techniques: Establishes, controls and verifies process capability and product characteristics, where applicable.

Thermal Design: S/C

- Surface charging requires outer layer electrical resistance $< 10^9$ ohm/sq
- Deployable sunshade & S/A shadow bus, instrument from sun while observing
- Sunshade is MLI, outer layer of side facing sun is ITO/silver teflon.
- S/A contains ~40%/60% cell/ITO silver teflon facing sun, MLI on back.
- Electronics boxes on hub, deck radiate most heat directly to space from cover (white paint). Box radiators sized to keep box at midpoint of req't range (20C).

Configuration Management

Safety & Mission Assurance

- Features
  - Closed Loop
  - Links Documents
  - Searches and Sorts Made Easy
  - Information Available On Demand 24 Hours A Day via WWW
  - Real Time Management Review
  - Single Point Collection and Status
  - Incorporates ISO 9001
  - Configuration Control Board Fully Represented

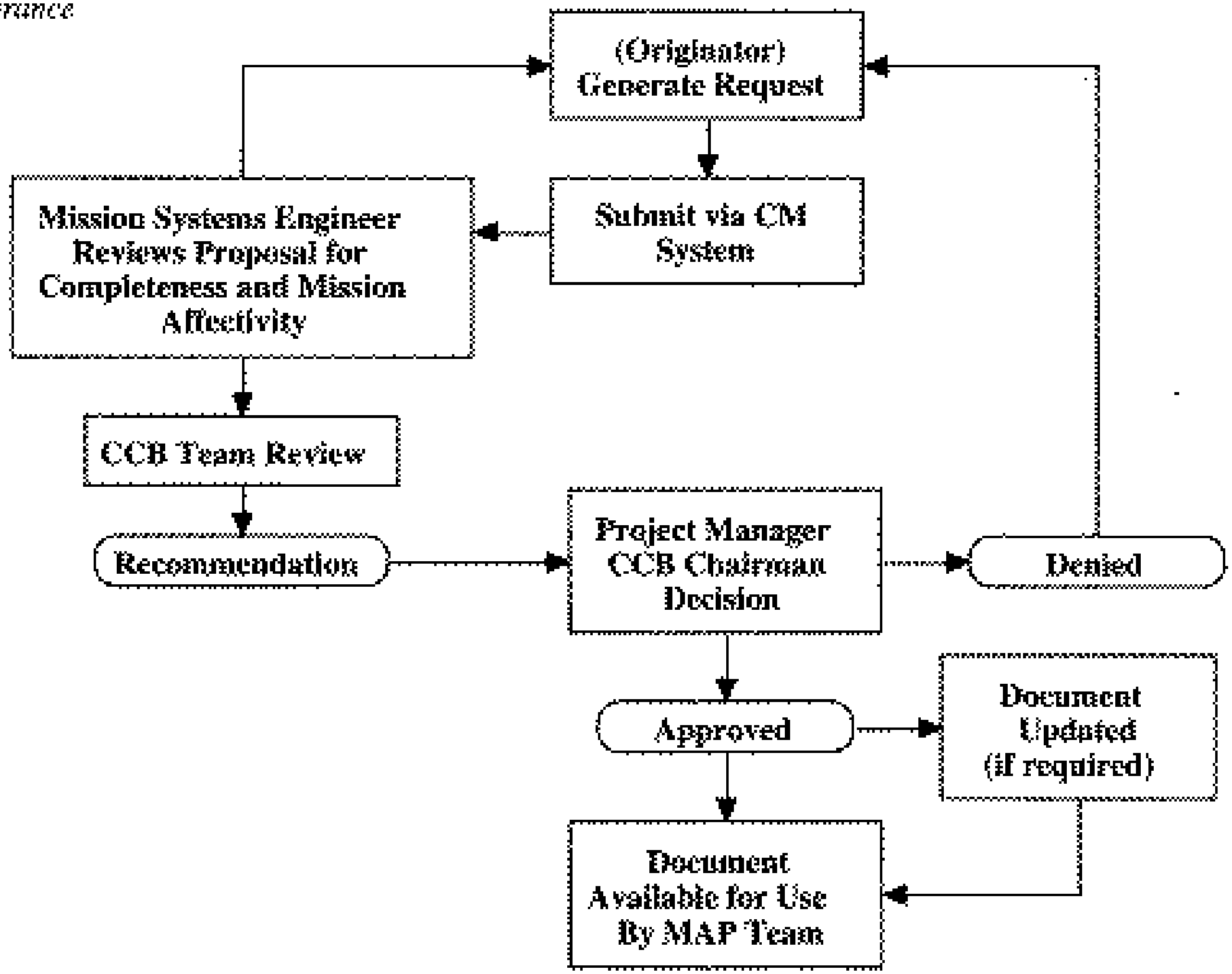
Configuration Management

- Strengths
  - Real Time Configuration Status
  - WWW CM System is Integrated with Mission Team Database
  - Self-Policing Configuration System
  - Document Submission via WWW
  - Complete Document Configuration Control
  - Automated E-Mail Notification of Changes

- Web Document Submittal
  - Documents Submitted Through Web Page (Step by Step Process)
  - Change Control Request (CCR) and Engineering Order (EO) Tied Directly To Real Time Document Database

MAP Configuration Process Flow

Safety & Mission Assurance

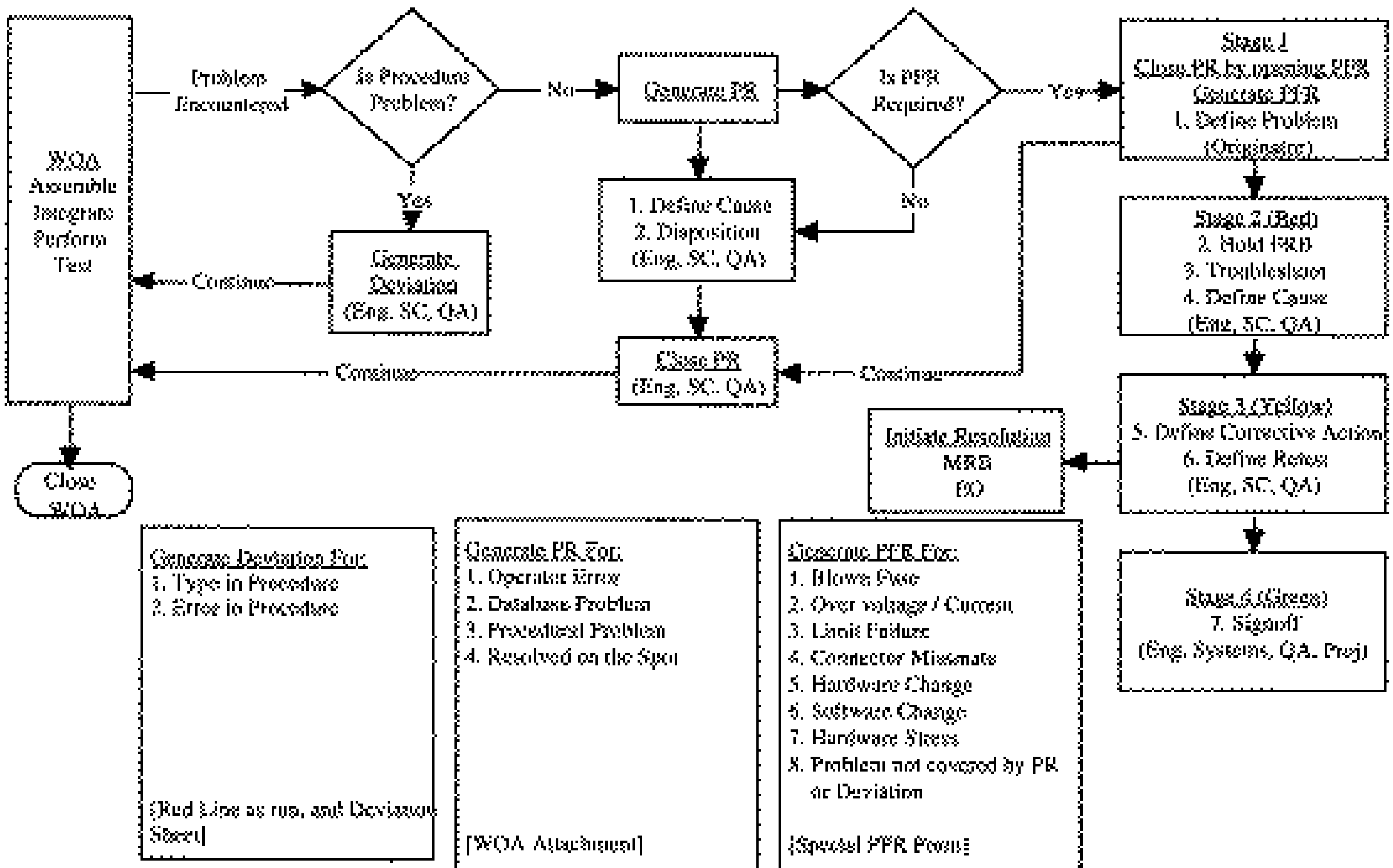


Problem Failure Reporting (PFR)

Safety & Mission Assurance

- Closed Loop
- Links Documents
- Searches and Sorts Made Easy
- Information Available On Demand 24 Hours A Day via WWW
- Single Point Collection and Status
- Password Protection Provided
- After Initial Generation of PFR, Flexibility To Use Electronic or Paper Systems
- PFR System Available To <u>All</u> MAP Team Members (includes NRAO / P.U.)
- Similar System Used On XTE and EUVE Projects (Value Added)

Problem Flow Chart



EEE Parts

- EEE Parts @ Grade 3 Level and Screening per 311-INST-001 Instruction.
- Parts Selection
  - PPL-21 or MIL-STD-975 Wherever Possible
  - Military Spec Preferred Over Non-Mil
  - Established Reliability (ER) Parts Preferred
  - TID <27 Krads, Single Event Effects
- Parts List
  - Preliminary
  - Updates
  - As Built
- No NSPARS (Non-Standard Parts Approval Request)

Parts Approval Process

- Contractor Holds Parts Evaluation Board (PEB)
- GSFC Parts Engineer Provides Independent Assessment
- Any Part Not Meeting Grade 3 Requirements Must Be Approved By PEB and GSFC Is Notified
- Project Team Evaluates Any Nonconforming Part and Is Responsible For Usage.
  - Options:
    - Agree With PEB
    - Give Technical Direction

Materials

Safety & Mission Assurance

- Review of materials and processes lists for all MAP assemblies for outgassing, flammability and other concerns (e.g.., glass transition temperature, fatigue life).
- Data on material properties is determined from existing literature or, if appropriate, testing is performed.
- Based on data or test results, negotiate with subsystems to :
  - Determine suitability of a material for a given application;
  - Provide assistance with alternate material selection when necessary.

Safety-Related Design Criteria

- Design to Tolerate Failures:

  – System failures posing a catastrophic hazard [may cause death or major system destruction] will be dual fault tolerant.

  – System failure posing a critical hazard [may cause severe injury or major property damage] will be single fault tolerant.

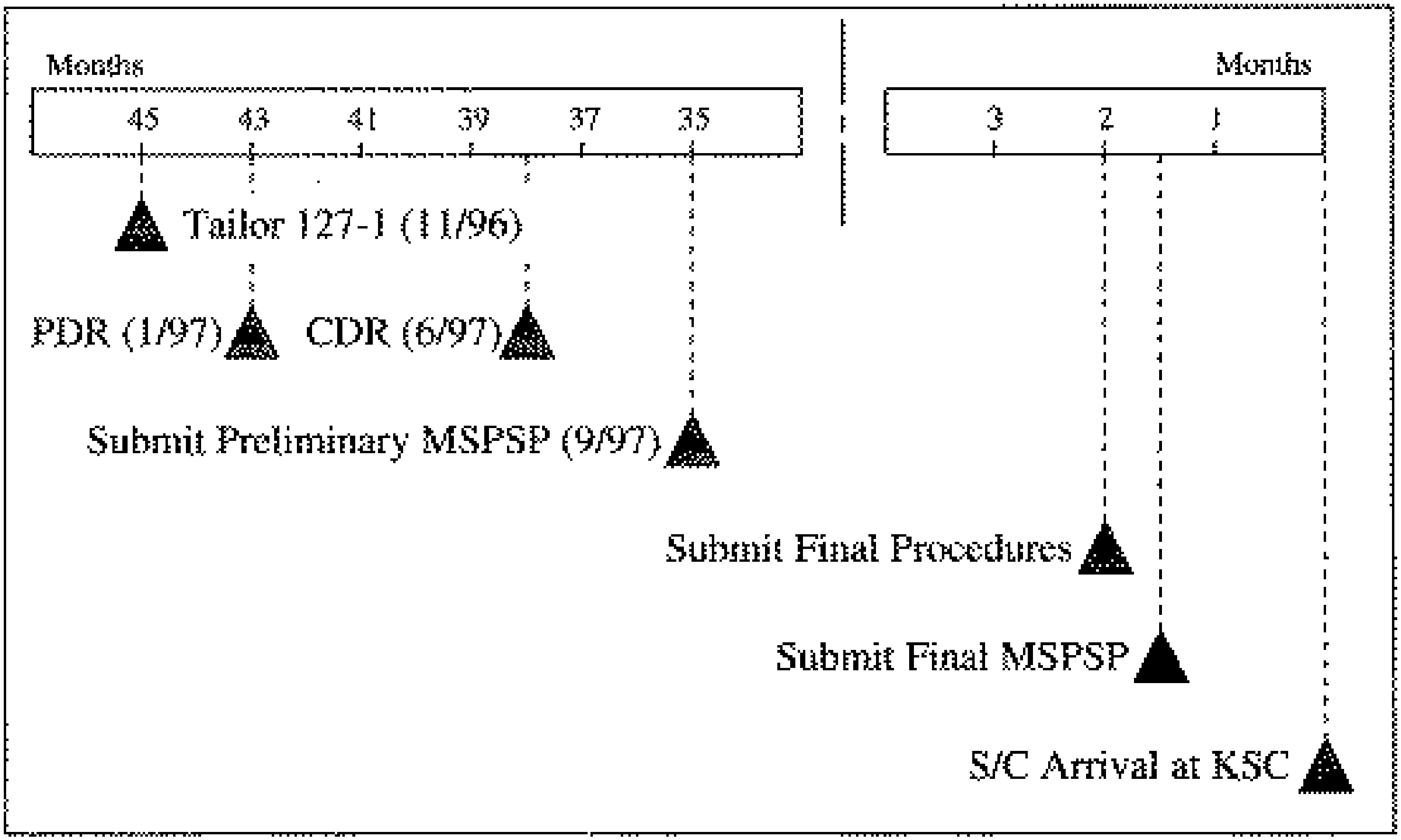
Safety Requirements

Safety & Mission Assurance

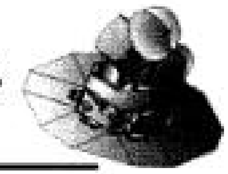
- Flight and Ground Requirements:
  - Range Safety Requirements Document - EWR 127 (tailored)
- Ground Requirements:
  - KSC Ground Safety Requirements Document - KHB 1710.2C
- Develop Missile System Prelaunch Safety Package (MSPSP) to Document Satisfaction of These Requirements

MAP Safety Data Submission Schedule

Safety & Mission Assurance



MAP Summary of Hazards and Controls



Safety & Mission Assurance

No.	Hazard Description	Type	Hazard Controls
1	Rupture of propellant tank	Cat.	- design/inspect/test per 127-1 - use approved materials - analyze/provide thermal control - pressurize per approved procedures and training - ensure appropriate labeling of all hardware
2	Material incompatibility with hydrazine	Cat.	- use materials compatible with hydrazine - maintain list of approved hydrazine-compatible materials - load fuel per approved procedures - ensure appropriate decontamination/cleaning process is used
3	Leakage or opening of thruster by command or mechanical failure	Cat.	- use of dual-seat thrusters - provide isolation valve for use during transport to pad - design/verify 3 electrical inhibits to inadvertent thruster firing - perform vibration test - load fuel per approved procedures/training

Summary of Hazards and Controls

Safety & Mission Assurance

No.	Hazard Description	Type	Hazard Controls
4	Structural failure of S/C Structure	Crit.	- design/analyze/inspect/test per 127-1 - use approved materials
5	Failure of Reaction Wheel Assembly	Cat.	- design/inspect/test per 127-1 - use approved materials - use of two independent electronic overspeed protection circuits - physically limit back EMF at the wheel motor - fracture control verification on all critical parts
6	Failure of battery NiH2	Cat.	- design/analyze/inspect/test per 127-1 - operate/handle battery per approved procedures/training - use scoop-proof connectors - provide signal line protection/fusing

Summary of Hazards and Controls

Safety & Mission Assurance

No.	Hazard Description	Type	Hazard Controls
7	Failure of MGSE (slings, dollies, etc...)	Cat.	- design/analyze/inspect/test per 127-1 - ensure appropriate procedures/training
8	S/C electrical	Crit.	- design/analyze/inspect/test per 127-1 - conformally coat circuit boards - all switches and relays hermetically sealed
9	RF	Crit.	- design/test per 127-1 and range limits - ensure approved procedures/training/clearances during testing
10	Ignition of flammable materials	Cat.	- no flammable gases are used - use approved materials
11	Failure of EGSE	Cat.	- design/analyze/inspect/test per 127-1 - explosion proof during/after fueling and at pad - protect against power surges - protect against mismating of connectors
12	Inadvertent deployment of solar arrays	Crit.	- ensure use of approved procedures/training - design/analyze to eliminate/safeguard against inadvertent deployment, no EED's

Conclusion

- The controls and processes are in place to support development and Observatory I&T.

- The parts, materials and safety programs are mature. All technical issues are being addressed with the appropriate subsystems.

PLANNING AND CONTROL

RICHARD DAY
PROJECT MANAGER

- L. ABBOTT - GSFC RESOURCE ANALYST
- S. DAWSON - PRINCETON BUSINESS SUPPORT
- H. KELLER - GSFC RESOURCE ANALYST
- J. TOMASELLO - GODDARD CONTRACTING OFFICER
- R. CORONEL - GODDARD PLANNING & SCHEDULING
- A. SCHUNEMANN - GODDARD NETWORK ADMINISTRATION

AGENDA

- OVERVIEW
- WORK BREAKDOWN STRUCTURE
- RESOURCE PLANNING
- PROGRAM CONTROLS
- TECHNICAL RESOURCES
- SCHEDULE RESOURCES
- HUMAN RESOURCES
- FINANCIAL RESOURCES
- REPORTING
- HERITAGE

INTEGRATED RESOURCE PLANNING & CONTROL

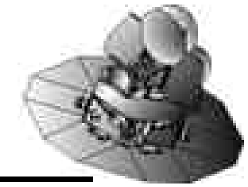
- WORK BREAKDOWN STRUCTURE (WBS) PROVIDES THE FOUNDATION
  - DEFINED TO 4 LEVELS (DELIVERABLE COMPONENTS)
- TECHNICAL RESOURCES
  - PERFORMANCE, MASS, POWER, FUEL, TELEMETRY
- SCHEDULE RESOURCES
  - COMPREHENSIVE, HIGHLY INTEGRATED SCHEDULE NETWORK
- HUMAN RESOURCES
  - FTE STAFFING PER WBS BY INDIVIDUAL & FISCAL YEAR
- FINANCIAL RESOURCES
  - BUDGETS DEVELOPED PER WBS WITH SEPARATE BUDGET LINE ITEMS FOR EACH UNDERLYING TASK OR PURCHASE

WORK BREAKDOWN STRUCTURE (WBS)

- WBS DEFINED TO 4 LEVELS
  - 1 **MISSION** (IMAGE AND MAP SHARE UPN 287)
    - 2 **MAJOR ELEMENT**
      - 3 **SUBSYSTEM**
        - 4 **COMPONENT**
- PRODUCT-ORIENTED, HIERARCHICAL DIVISION OF DELIVERABLE ITEMS AND ASSOCIATED SERVICES
- FOUNDATION FOR PROJECT PLANNING, ORGANIZATION, IMPLEMENTATION & CONTROL
  - INCLUDING RISK MANAGEMENT

WORK BREAKDOWN STRUCTURE (WBS)

Planning and Control



MAP MISSION UPN 287-1

PROJECT MANAGEMENT 287-11
-1 Science Team & Science Support
-2 Plan, Org, Implemen. & Control
-3 Education & Public Outreach

SYSTEM ENGINEERING 287-12
-1 Sys-level Analytical Integ.
-2 Mission System Engr.

PERFORMANCE ASSURANCE 287-13
-1 Parts Engineering
-2 Materials Engr.
-3 Quality Assurance
-4 Safety & Reliability

"SPACECRAFT" SUBSYSTEMS 287-14
-1 Attitude Control
-2 Command & Data Handling
-3 Power
-4 Communications
-5 Electrical Interconnection
-6 Structural/Thermal
-7 Flight Software
-8 (intentionally blank)
-9 "Spacecraft" I&T

"INSTRUMENT" SUBSYSTEMS 287-15
-1 Structural/Thermal
-2 Spacecraft Mission Uniques
-3 Electronics
-4 Thermal Reflector System
-5 (intentionally blank)
-6 "Instrument I&T
-7 Differencing Assemblies

GROUND SEGMENT 287-16
-1 Development
-2 I&T Systems
-3 Science/Mission Operations Center

SYSTEM INTEG. I&T 287-17
-1 Integration & Perf. Testing
-2 Environmental Testing
-3 Transport Operation
-4 Launch Site Operations
-5 Integrated Vehicle Operations
-6 Launch & In-Orbit Checkout

LAUNCH VEHICLE 287-18
-1 Basic
-2 Mission Uniques
-3 Aircraft Coverage

MISSION OPS & DATA ANALYSIS 287-19
-1 Ops. Preparations
-2 Flight Operations
-3 Office of the MAP Exp. Gen. Archive
-4 Data Analysis Preparations
-5 Flight Software Maintenance
-6 Ground Segment Maintenance
-7 Network Operations

CONTINGENCY 287-10
-1 Technical Margin
-2 Schedule Margin

RMD 5/6/97

RESOURCE PLANNING

- SAME PROCESS FOR ALL RESOURCES
- PRODUCT TEAM LEADER CONDUCTS GRASS ROOTS ESTIMATION OF REQUIREMENTS
  - NEGOTIATES DEPENDENCIES AS REQUIRED
- RESOURCE ANALYST (RA) OR SYSTEM ENGINEER (SE) WORKS WITH PRODUCT TEAM LEAD TO ANALYZE INPUTS, REFINE DEPENDENCIES AND CONSTRUCT PROPOSED BUDGET ALLOCATIONS
- RA/SE ANALYZES BUDGET REQUEST IN CONTEXT OF OVERALL MISSION AND PROVIDES ANALYSIS & RECOMMENDATIONS TO PROJECT MANAGER
- PROPOSED PLAN IS PRESENTED TO PROJECT MANAGER FOR DISCUSSION AND APPROVAL

PROGRAM CONTROLS

- STRICT PROGRAM CONTROLS ARE APPLIED
  - BASELINE REQUIREMENTS AND PHASED PLAN
    - CHANGE HISTORY IF REQUIRED
  - CURRENT STATUS RELATIVE TO PLAN
  - PROJECTION AT COMPLETION
  - ACTUAL AT COMPLETION IS DOCUMENTED

- RESPONSIBILITY IS DELEGATED TO PRODUCT TEAM LEADS TO THE GREATEST EXTENT POSSIBLE WITHOUT WEAKENING THE REQUIRED CENTRALIZED PROJECT CONTROL
  - VARIES WITH PROGRAM PHASE AND INDIVIDUAL EXPERIENCE AND PERFORMANCE

TECHNICAL RESOURCE MANAGEMENT

- TECHNICAL RESOURCES INCLUDE:
  - SENSITIVITY
  - DATA LOSS
  - SPATIAL RESOLUTION
  - SYSTEMATIC ERROR
  - MASS
  - POWER
  - PROPELLANT
  - TELEMETRY BANDWIDTH

- ALLOCATIONS CENTRALLY CONTROLLED BY PROJECT VIA CONFIGURATION CHANGE BOARD (CCB)

SCHEDULE MANAGEMENT

Planning and Control

- COMPREHENSIVE
  - 3200 ACTIVITIES
- HIGHLY INTEGRATED
  - 3800 RELATIONSHIPS BETWEEN ACTIVITIES
- OVER 200 PROGRAM CONTROL MILESTONES ARE HARD CODED INTO NETWORK
- COMPONENT DEVELOPMENT AND SYSTEM I&T ACTIVITY FLOWS ARE VERY DETAILED
  - DURATIONS BASED ON EXPERIENCE WITH SIMILAR PROJECTS
- NETWORK IS STATUSED MONTHLY BASED ON PRODUCT TEAM PROGRESS
  - GANTT CHARTS UPDATED BASED ON NETWORK DATA

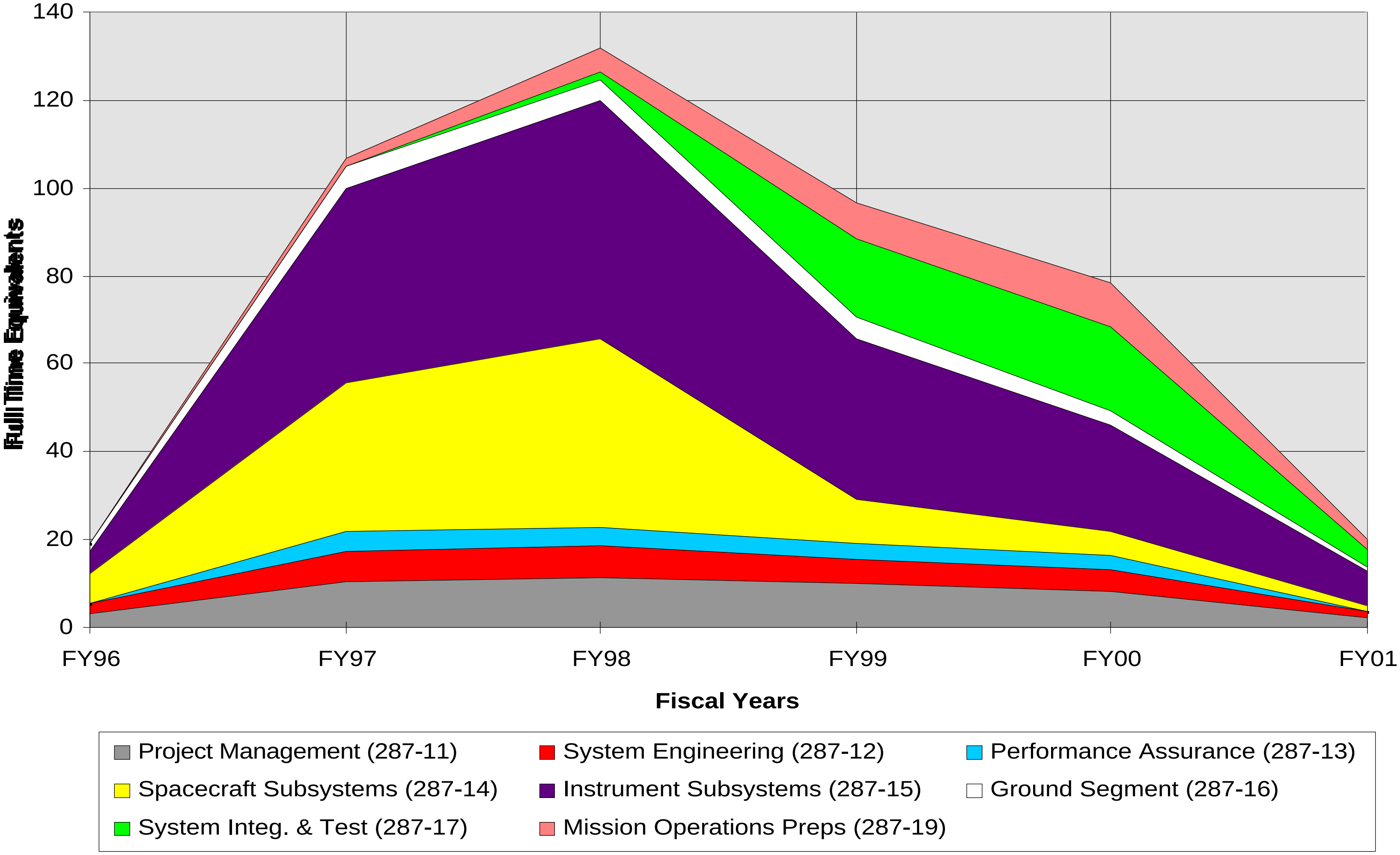
INSERT SCHEDULES

HUMAN RESOURCES MANAGEMENT

- STAFFING PLANS
  - FTE PLAN BY INDIVIDUAL NAME, BY FISCAL YEAR
    - CIVIL SERVANTS, SUPPORT CONTRACTORS, PRINCETON, UCLA, CHICAGO, NRAO
- CIVIL SERVANT LABOR CHARGES EVALUATED MONTHLY BY PRODUCT TEAM LEADS
  - APPARENT INCORRECT CHARGES (OVER OR UNDER) ADDRESSED WITH FUNCTIONAL LINE MANAGERS
- PRINCETON, NRAO, AND SUPPORT SERVICE CONTRACTOR LABOR CHARGES EVALUATED BASED ON MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT (533)
  - EVALUATED AGAINST BASELINE AND ANY DISCREPANCIES ADDRESSED

STAFFING PROFILE BY WBS ELEMENT

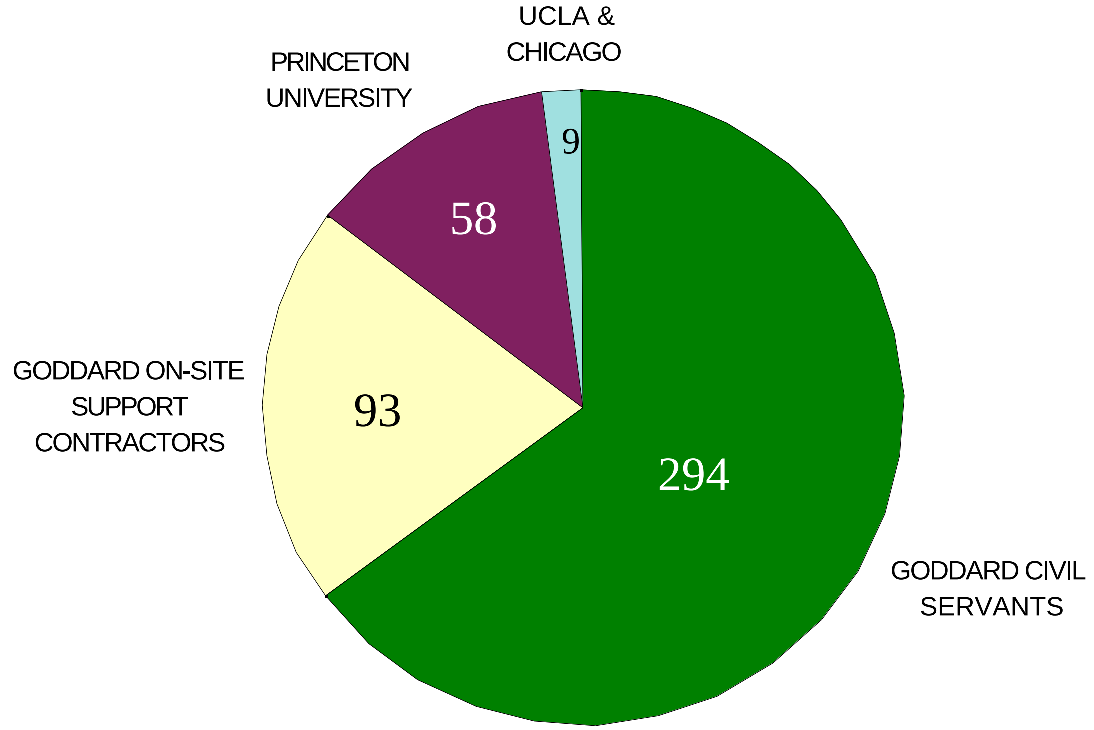
Planning and Control



Includes civil servants, on-site contractors, Princeton, Chicago, UCLA

STAFFING TOTAL BY INSTITUTION

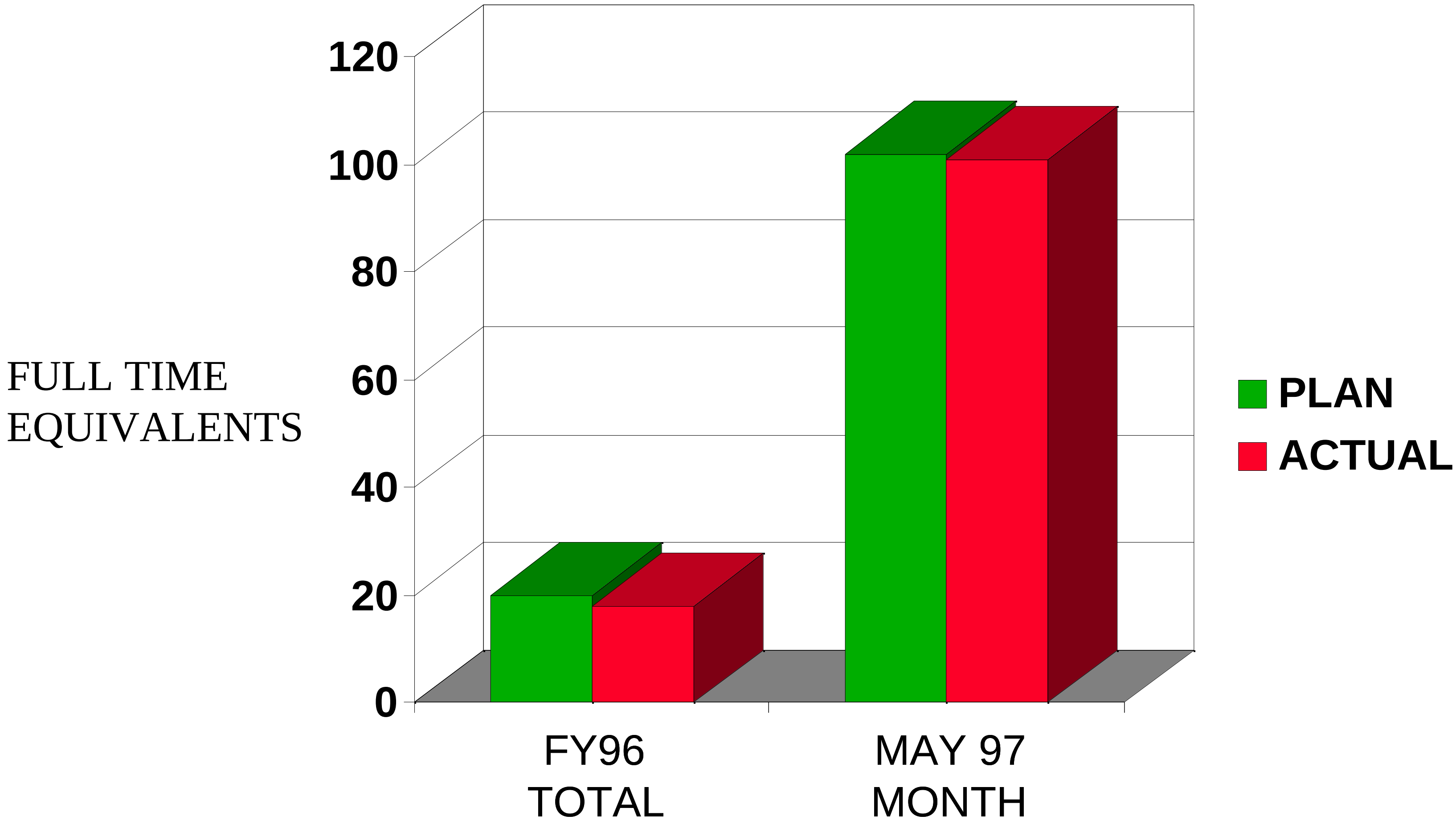
TOTAL FULL TIME EQUIVALENT (FTE) STAFFING
FROM MISSION SELECTION THROUGH LAUNCH



TOTAL STAFFING = 454 FTE

STAFFING PLAN VS ACTUAL

Planning and Control



INCLUDES CIVIL SERVANTS, ON-SITE CONTRACTORS AND PRINCETON

FINANCIAL RESOURCE MANAGEMENT

- GUIDING PRINCIPLES:
  - DESIGN TO MINIMIZE TOTAL LIFE CYCLE COST
  - SPEND ONLY WHAT IS NEEDED
  - UNUSED FUNDS WILL NOT BE LOST IF NEEDED LATER
    - PRODUCT TEAMS ASSISTED IN GENERATING CONTINGENCY TOWARD PRODUCT COST AT COMPLETION
- BUDGET PLANNING
  - THOROUGH GRASS ROOTS ESTIMATION PROCESS
    - SEPARATE BUDGET LINE ITEMS FOR EACH UNDERLYING CONTRACT, TASK OR PURCHASE OF EACH WBS ELEMENT
  - EXECUTIVE ESTIMATION BASED ON ASSESSMENT OF RISKS AND RAO PARAMETRIC ESTIMATION
  - BUDGET PLAN IS CLOSELY CORRELATED TO TECHNICAL BASELINE AND ASSOCIATED DETAILED SCHEDULE AND STAFFING PLAN

FINANCIAL RESOURCE MANAGEMENT (CONTINUED)

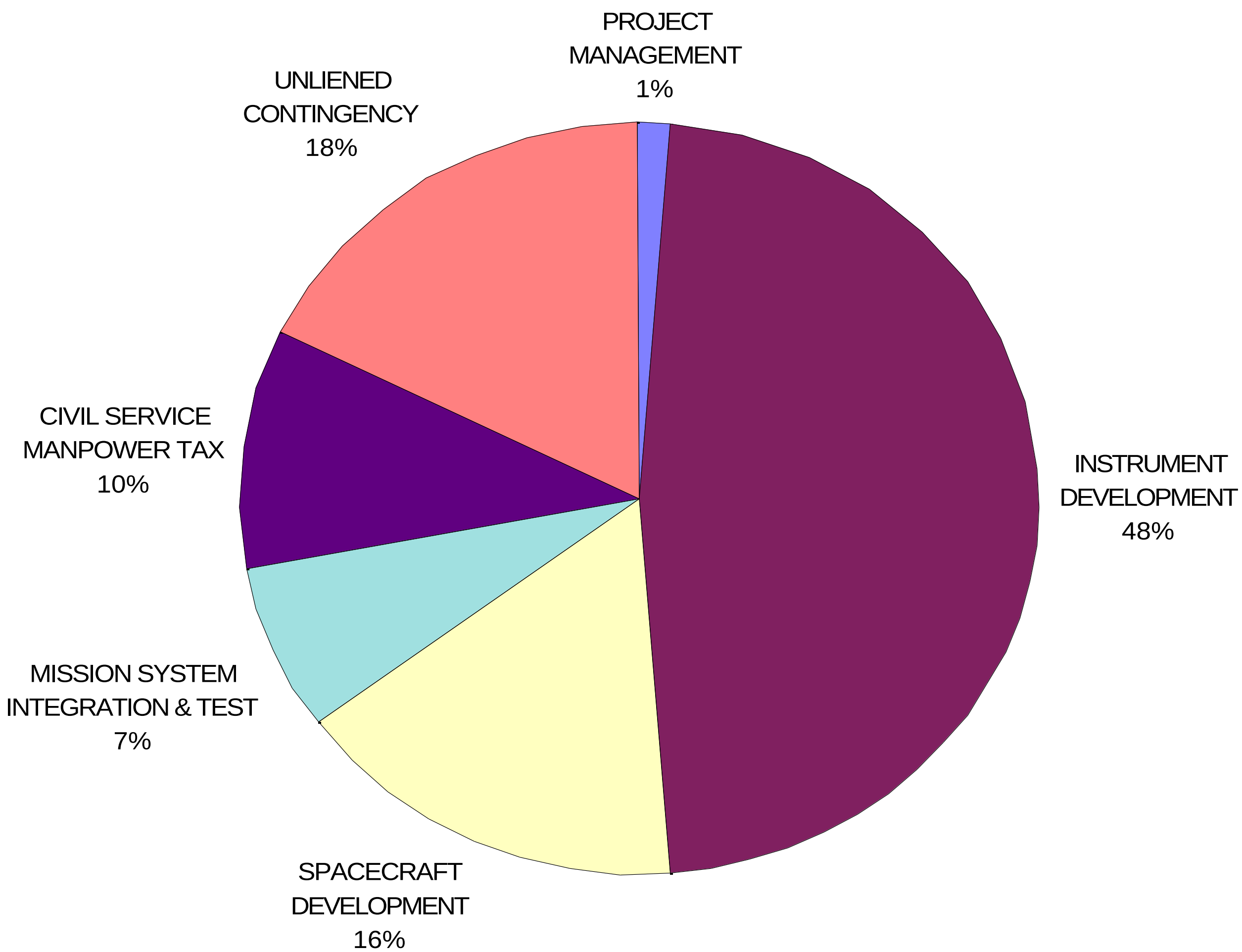
- BUDGET CONTROL
  - EVERY GODDARD EXPENDITURE IS CLOSELY MONITORED BY PRODUCT TEAM LEADS, RESOURCE ANALYSTS AND/OR PROJECT MANAGER
  - EVERY PRINCETON EXPENDITURE IS REVIEWED BY PRINCETON BUSINESS MANAGER
    - FLIGHT PURCHASES APPROVED BY FLIGHT ASSURANCE MGR.
    - PURCHASES >$1k REVIEWED BY INSTRUMENT SCIENTIST AND SUBJECT TO INVENTORY SCREENING
  - PRINCETON, NRAO, AND SUPPORT SERVICE CONTRACTOR CHARGES EVALUATED BASED ON MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT (533)
    - QUARTERLY 533s PROVIDE UPDATED PROJECTION OF COST AT COMPLETION

NOA & COST REQUIREMENTS

Planning and Control

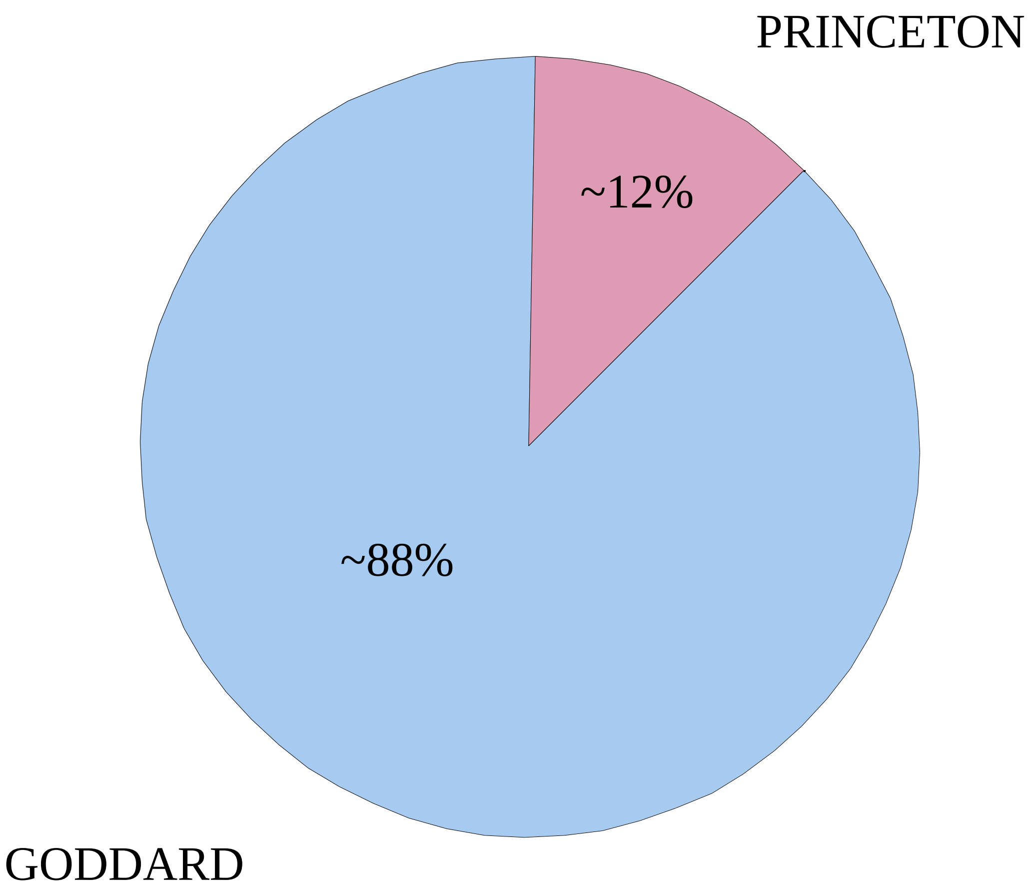
	PRIOR YRS	FY97	FY98	FY99	FY00	FY01	TOTAL AT COMPL.
UNCOSTED AT END OF FY	**4,541**	**9,753**	**7,967**	**6,958**	**6,261**	**0**	**0**
NOA	**5,400**	**15,700**	**20,800**	**22,800**	**17,300**	**6,300**	**88,300**
COST	**859**	**10,488**	**22,586**	**23,809**	**17,997**	**12,561**	**88,300**
COSTS BY ELEMENT:							
PROJECT MANAGEMENT:	**0**	**15**	**293**	**500**	**420**	**0**	**1,228**
INSTRUMENT:	**778**	**8,314**	**12,015**	**8,874**	**6,631**	**2,105**	**38,717**
SPACECRAFT:	**81**	**1,233**	**7,657**	**3,008**	**1,100**	**0**	**13,079**
MISSION SYSTEM I&T:		**208**	**578**	**1,738**	**2,534**	**1,025**	**6,083**
MPS:		**718**	**1,943**	**2,889**	**1,948**	**931**	**8,429**
CONTINGENCY:			**100**	**6,800**	**5,364**	**8,500**	**20,764**
TOTAL COST	**859**	**10,488**	**22,586**	**23,809**	**17,997**	**12,561**	**88,300**

COST BY ELEMENT

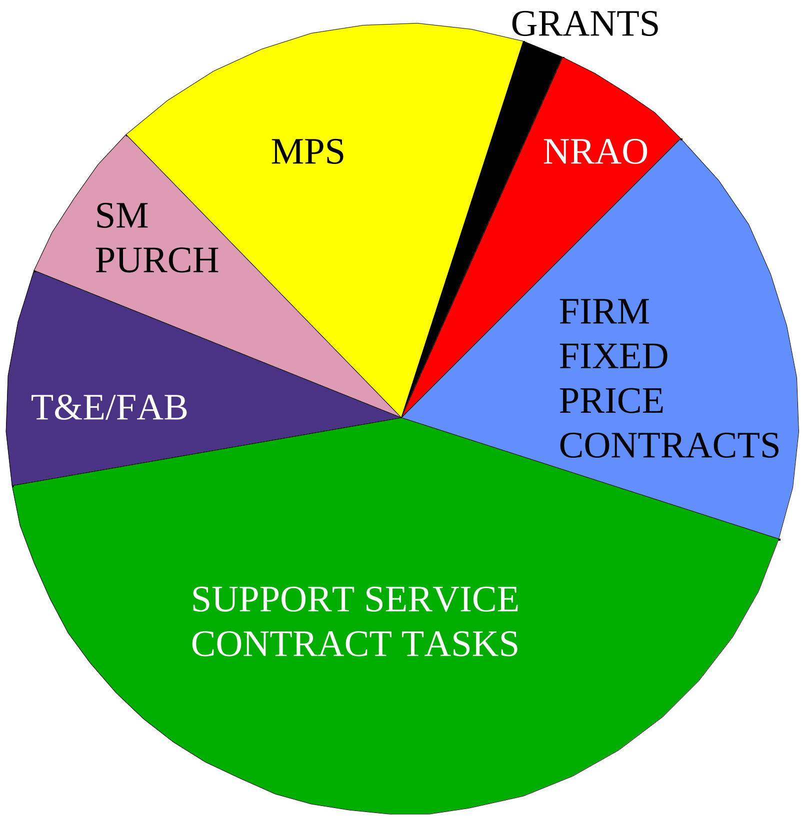


EXPENDITURES BY PARTNER

Planning and Control



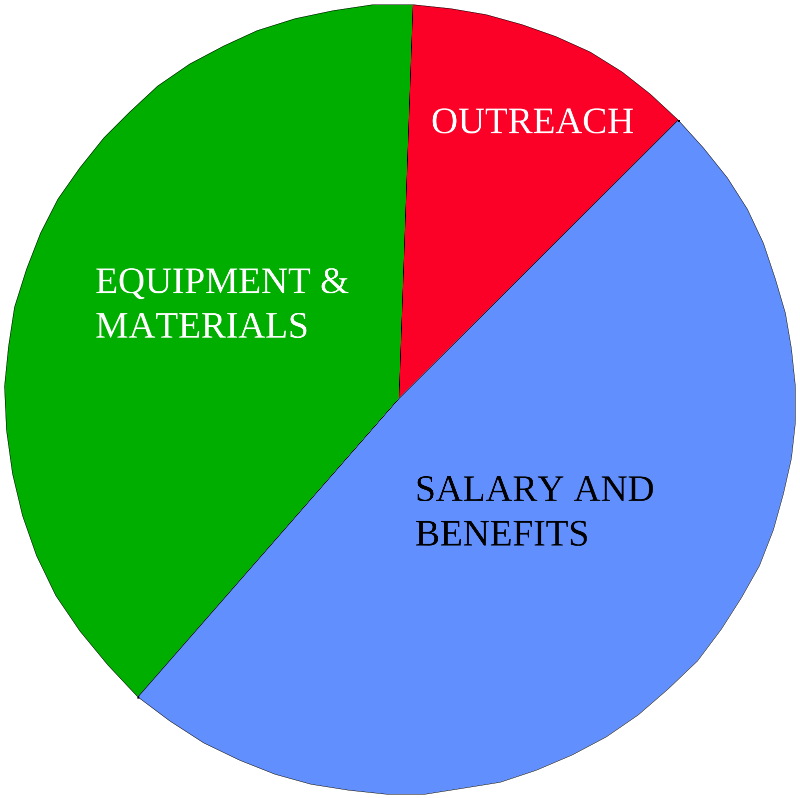
GODDARD EXPENDITURES
BY CATEGORY



PRINCETON EXPENDITURES

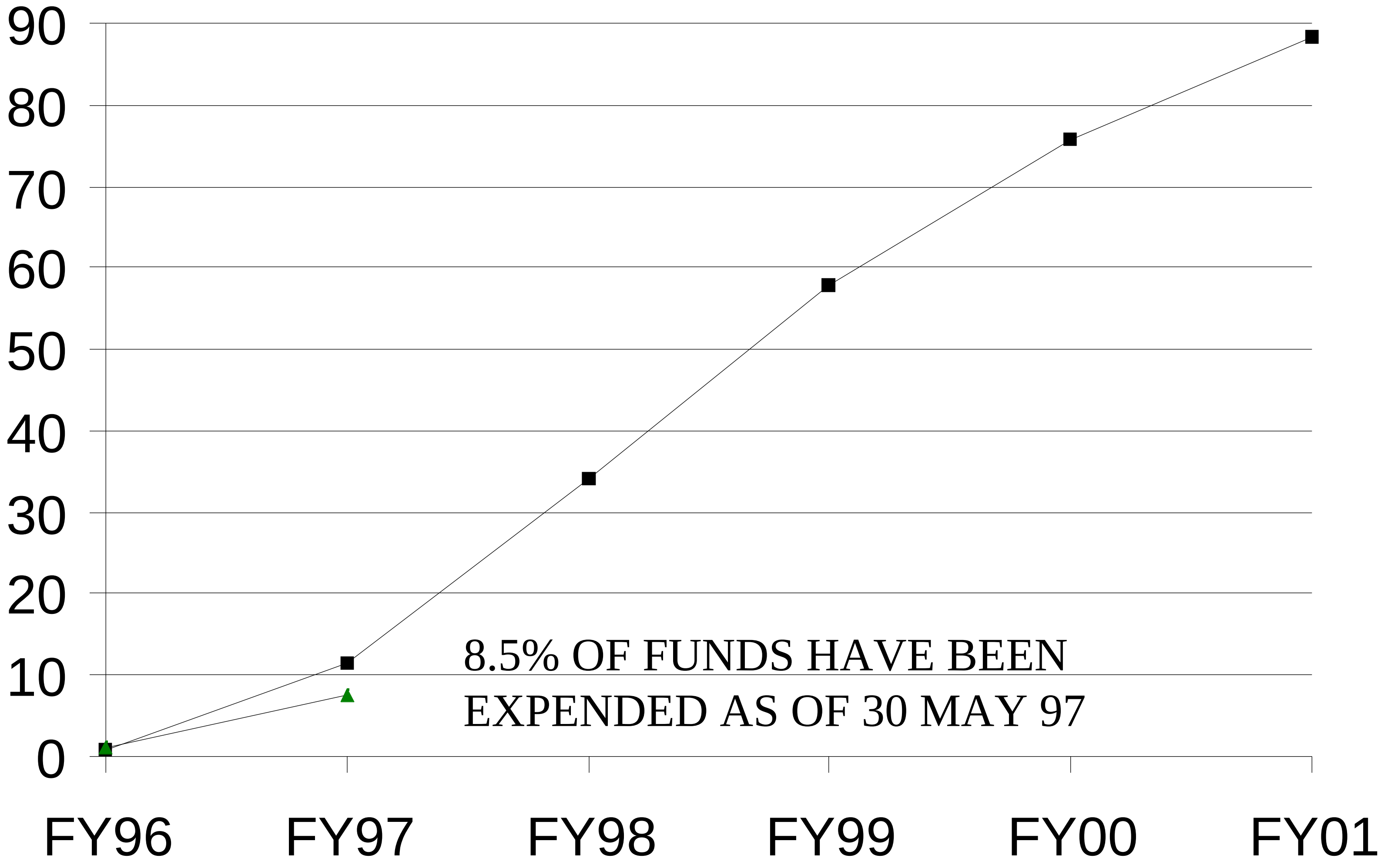
BY CATEGORY

Planning and Control



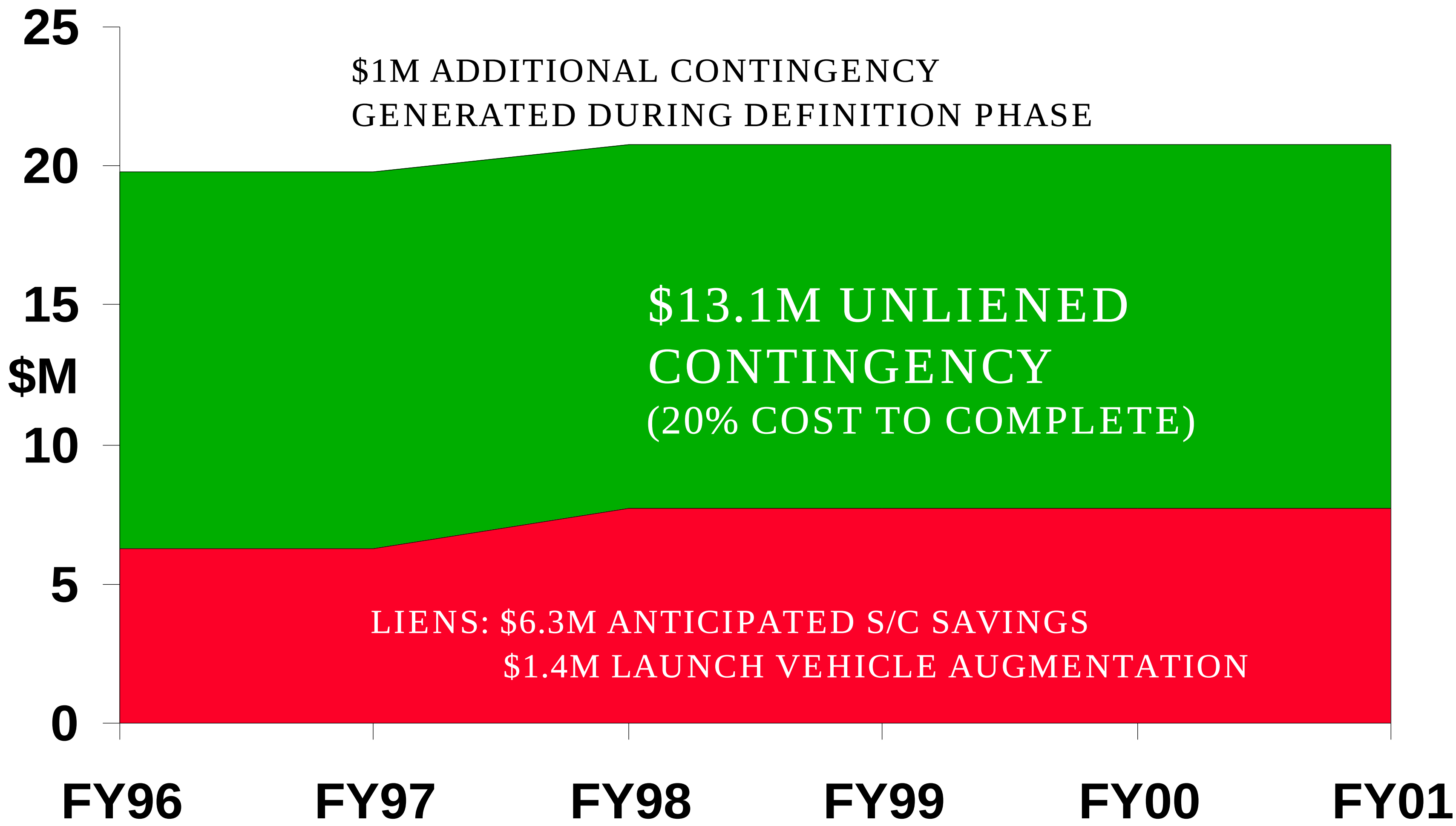
CUMULATIVE COST

Planning and Control



FINANCIAL CONTINGENCY

Planning and Control



MO&DA REQUIREMENTS

	FY 00 (FY94$)	FY01 (FY94$)	FY02 (FY94$)	FY03 (FY94$)	TOTAL (FY94$)
MAP UNIQUE	$0.7M	$2.3M	$1.9M	$1.7M	$6.6M
MIDEX GENERIC		$0.8M	$0.7M		$1.5M
TOTALS	$0.7M	$3.1M	$2.6M	$1.7M	$8.1M

- MIDEX MO&DA LIMIT: $15M(FY94)
- MAP PROPOSAL, $6.6M (FY94), ASSUMED NASA-PROVIDED SPACECRAFT OPERATIONS WERE SEPARATELY FUNDED
  - NOT THE INTENTION OF MIDEX PROGRAM BUT PROPOSERS TOLD TO DOCUMENT ASSUMPTIONS
  - ACCOUNTS FOR REMARKABLY LOW PROPOSED BUDGET
  - ABSORBING GENERIC BUDGET WOULD ELIMINATE ALL FORMS OF MAP MO&DA BUDGET MARGIN
- TOTAL REQUIREMENTS WITHIN CURRENT BUDGET LINE ITEM ASSUMPTION FOR MIDEX 2 MO&DA AND MIDEX MO&DA LIMIT
- PLAN TO PROPOSE REQUIRED ADJUSTMENT TO GSFC AND HQ PROGRAM EXECUTIVES THROUGH CONFIRMATION PROCESS

MO&DA ASSUMPTIONS

- TINY ROUTINE FLIGHT OPERATIONS STAFF (BASELINE=3)
  - MAXIMAL USE OF FLIGHT & GROUND SYSTEM AUTONOMY
  - DEVELOPMENT TEAM CONDUCTS IN-ORBIT CHECKOUT AND MISSION OPERATIONS UNTIL NOMINAL ORBIT AT L2 IS ACHIEVED (L+3 MONTHS)
  - CIVIL SERVICE SUPPORT FOR PERIODIC MOMENTUM UNLOADING AND FLIGHT SOFTWARE MAINTENANCE
  - COMBINED SCIENCE/MISSION OPERATIONS CENTER WITH IMAGE
- MO&DA FUNDS OPERATIONS BEGINNING AT L+31 DAYS
  - 27 MONTH BASELINE MISSION FROM LAUNCH PLUS
  - 1 ADDITIONAL YEAR OF DATA ANALYSIS
- MAP MO&DA REQUIREMENTS <u>DO NOT</u> INCLUDE:
  - DEEP SPACE NETWORK SUPPORT
  - NASCOM SUPPORT

<u>ASSUMED TO BE BUDGETED SEPARATELY BY CODE S</u>

EXTENDED MO&DA

- COBE OPERATIONS WERE PLANNED FOR 1 YEAR AND EXTENDED TO 4 YEARS

- MAP WILL RECOMMEND THE NASA OFFICE OF SPACE SCIENCE CONSIDER PROGRAMMING APA FUNDS (ALLOWANCE FOR PROGRAM ADJUSTMENT) IN FY03-06 FOR MAP EXTENDED OPERATIONS

INTERNAL REPORTING

Planning and Control

- FOCUSED WEEKLY MEETINGS AND TELECONS
- MONTHLY PRODUCT TEAM STATUS REVIEWS
  - TECHNICAL ACCOMPLISHMENTS
  - TECHNICAL CHALLENGES AND ISSUES
  - SCHEDULE STATUS
    - GANTT AND PERT NETWORK REVIEW
    - SLACK SUMMARY AND CHANGES/TREND
    - MILESTONE TRACKING
  - STAFFING ACTUALS VS. PLAN BY NAME
  - COST STATUS
    - CUMULATIVE COST ACTUAL VS. PLAN
    - 533 ANALYSIS SUMMARY
    - AFFIRMATION THAT COST AT PROJECTED COMPLETION REMAINS WITHIN BUDGET ALLOCATION
    - IDENTIFICATION OF ANY COST PHASING ISSUES

EXTERNAL REPORTING

- WEEKLY GSFC TOP 10 INPUTS
- MONTHLY PROJECT STATUS REVIEW
  - GSFC ASSOC. DIRECTOR FOR SPACE SCIENCE PROGRAMS
  - NASA HQ OFFICE OF SPACE SCIENCE PROGRAM EXECUTIVES
- QUARTERLY PROGRAM MANAGEMENT COUNCIL REVIEWS
  - GSFC DEPUTY DIRECTOR
  - GSFC EXECUTIVE COUNCIL
  - NASA HQ OFFICE OF SPACE SCIENCE PROGRAM EXECUTIVES
- HQ PROGRAM EXECUTIVES PROVIDE MONTHLY SUMMARY AND INDEPENDENT ASSESSMENT TO THE NASA ASSOCIATE ADMINISTRATOR FOR SPACE SCIENCE

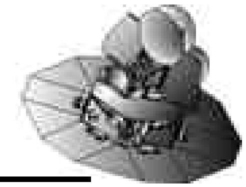
EXTERNAL REPORTING
(CONTINUED)

- CONTENT OF MONTHLY/QUARTERLY REVIEWS:
  - PROJECT MANAGER ASSESSMENT
  - SUMMARY FEVER CHART OF MAJOR ELEMENTS AND SUBSYSTEMS (CURRENT AND 2 PAST MONTHS)
  - SIGNIFICANT PROGRESS
  - PROBLEMS/ISSUES
    - PROGRAMMATIC IMPACT
    - ACTION PLAN WITH COMPLETION DATES
    - CURRENT STATUS OF RESOLUTION
  - TECHNICAL RESOURCE STATUS (MASS, POWER, FUEL)
  - SCHEDULE STATUS
    - MASTER GANTT
    - SIGNIFICANT MILESTONES (CURRENT MONTH +8, -3)
    - MAJOR MILESTONE TOTAL SLACK SUMMARY

EXTERNAL REPORTING
(CONTINUED)

- CONTENT OF MONTHLY/QUARTERLY REVIEWS (CONTINUED):
  - FINANCIAL STATUS
    - COST ACTUAL VS. PLAN AND VARIANCE EXPLANATIONS
    - COST TO COMPLETE
    - OBLIGATION ACTUAL VS. PLAN AND VARIANCE EXPLANATIONS
    - CONTINGENCY STATUS INCLUDING HISTORY
    - CONTINGENCY ENCUMBRANCES AND LIENS
    - CONTINGENCY (LESS LIENS) ON COST TO COMPLETE

HERITAGE



PLANNING AND CONTROL APPROACH & TOOLS WERE UTILIZED ON XTE (X-RAY TIMING EXPLORER)

- Largest schedule underrun in database of projects
- Costs were $36M (16%) less than historical expectations

REFERENCE: INDEPENDENT RAO REPORT “XTE: A STANDARD OF EXCELLENCE” SEPTEMBER 1996

MAP Mission Confirmation Review

Resource Analysis Office

Parametric Cost Analysis Presentation

Cindy Fryer

June 17-19, 1997

MAP Mission
Cost Comparison
Phase B & C/D Real Year Millions
In-House Approach

	GSFC ESTIMATE	RAO ESTIMATE Unadjusted	Delta	Adjusted for potential S/C Savings
SPACECRAFT	$20.4	$28.5*	(6.3)	$22.2
INSTRUMENT	$38.7	$39.3		$39.3
SUBTOTAL	**$59.1**	**$67.8**		**$61.5**
MPS	$ 8.4	$ 8.4		$ 8.4
SUBTOTAL	**$67.5**	**$76.2**		**$69.9**
CONTINGENCY	$20.8*	$11.4	6.3	$17.7*
TOTAL W/ CONTINGENCY	**$88.3**	**$87.6**		**$87.6**
CIVIL SERVICE MANYEARS	**262**	**262**		**262**

*Contains potential spacecraft savings of $6.3

MAP Mission
Cost Comparison
Phase B & C/D Real Year Millions
In-House Approach

	GSFC ESTIMATE	RAO ESTIMATE Unadjusted	Delta	Adjusted for potential S/C Savings
S/C BUS (360 kg)	**$14.3**	**$20.4***	**(6.3)**	**$14.1**
SLT		$ 4.3		$ 4.3
MSI&T	$ 6.1	$ 3.8		$ 3.8
INTEGRATION TOTAL	**$ 6.1**	**$ 8.1**		**$ 8.1**
S/C TOTAL	**$20.4**	**$28.5**		**$22.2**
INSTRUMENT (231 kg)	**$38.7**	**$39.3**		**$39.3**
SUBTOTAL (591 kg)	$59.1	$67.8		$61.5
MPS	$ 8.4	$ 8.4		$ 8.4
SUBTOTAL	**$67.5**	**$76.2**		**$69.9**
CONTINGENCY	$20.8*	$11.4	6.3	$17.7*
MISSION TOTAL W/CONTINGENCY	**$88.3**	**$87.6**		**$87.6**
CIVIL SERVICE MANYEARS	**262**	**262**		**262**

*Contains potential spacecraft savings of $6.3

RAO Assessment

- The two estimates are very close.
- The GSFC MAP Project estimate of $88.3 is within the 10% error band associated with RAO's parametric estimate of $87.6 (RY millions).
- From a modeling perspective, parametric cost savings have been realized in the area of Mission System Integration and Test (MSI&T). This is due to the fact that GSFC is building the spacecraft and is also responsible for integrating the instrument to the spacecraft bus. MSI&T costs must be added to SLT costs to get total integration costs.

RAO Assessment

- GSFC is building the spacecraft bus and most of the instrument. Common teams for spacecraft and instrument subsystems have been formed. This has resulted in cost savings and reductions in the civil service manpower and may result in additional parametric spacecraft bus cost savings.
- The schedule appears feasible. The spacecraft is fine. However, the historical data indicates the instrument might be tight--management controls and risk mitigation options need to be in place in order to prevent schedule slip. A major slip may cause instrument cost growth.

RAO Assessment

- The RAO recommended amount of contingency for its parametric cost estimate is 15%. The mission is beyond Phase B and has advanced to its critical design review. At this stage, designs are mature, locked in, and there is less uncertainty.

RAO Recommendations

- The GSFC MAP Project estimate of $88.3 appears feasible as it falls within the 10% error band associated with RAO's estimate of $87.6 (RY millions).
- The schedule appears reasonable. Historical data indicates the instrument schedule might be tight. Management controls and risk mitigation options need to be in place to prevent instrument schedule slip and cost growth.
- Project estimate contingency appears adequate.

BACKUP MATERIAL

MAP
Major Ground Rules and Cost Assumptions

- Dollars are presented in RY millions and reflect an augmented hybrid build with 262 civil service manyears. The manpower number is from the most current 1997 Center Manpower Tracking System (MTS).
- Real year dollars were estimated with a conversion factor of 1.071 to get from 1996 dollars to real year dollars.
- The mission is scheduled to launch late in the year 2000.
- A fee of six percent was applied to the out-of-house estimate before converting to in-house dollars.
- A fifteen percent contingency is recommended because of the maturity of designs, the project has reached the critical design review (CDR).
- An out-of-house estimate was developed and converted to in-house dollars to reflect the current civil service manpower of 262 manyears.
- MAP civil service manpower is estimated to be 262 civil servants. Because of common spacecraft and instrument teams, there is an estimated savings of 114 civil servants. The conversion to an augmented hybrid dollar approach was based on 376 manyears (262 + 114). This was done because the RAO manpower model reflects the "old" way of doing business and does not account for the reduction in civil servants due to spacecraft and instrument teaming.
- Civil service manpower was not readily available at the spacecraft subsystem level because of the degree that the team is integrated across functional lines so in-house cost is provided at the total spacecraft bus level.

MAP
Major Ground Rules and Cost Assumptions

- The instrument was classified as a passive microwave with COBE DMR heritage. The SICM Cost Model was used and costs reflect a PROTOFLIGHT approach with some engineering models.
- The Small Spacecraft Cost Model was used to develop spacecraft costs.
- MSI&T was estimated assuming FAST heritage and was calculated at 15.5 percent of out-of-house spacecraft bus costs.
- Because GSFC is building and integrating the spacecraft and instrument to the bus, parametric savings are realized in MSI&T costs. To estimate total integration costs, MSI&T must be added to spacecraft SLT costs.
- The MPS number was provided by the project based on POP 97-1 MPS assessments.
- There are no traditional Phase B costs to add to the estimate because of the accelerated implementation mode of this mission.

MAP
Mission Dry Weight Summary

		kg.	lb.
BUS			
ACS		52.5	115.5
CC&DH		18.94	41.7
C&DH	11.70		
RF	7.24		
POWER		66.45	146.2
Elect. Harn.	25.30		
Power	41.15		
THERMAL		27.70	60.9
STRUCTURE		181.75	399.9
Structure	87.38		
Bracketry	22.93		
Deployables	56.30		
Bolts	5.14		
Balance	10.00		
PROPULSION		13.09	28.8
BUS TOTAL		360.43	793.0
INSTRUMENT		231.00	508.2
MISSION DRY TOTAL		591.43	1301.2

RISK MANAGEMENT

AGENDA

- FUNDAMENTALS OF APPROACH
- SUPPLIER RELATIONSHIP
- TECHNICAL RESOURCE RISK MANAGEMENT
- SCHEDULE RISK MANAGEMENT
- COST RISK MANAGEMENT
- RISK MANAGEMENT PROCESS
- TOP RISK AREAS AND MITIGATION PLANS
- DESCOPE PLAN

PURPOSE OF RISK MANAGEMENT

- VITAL INTEGRATION TECHNIQUE FOR PLANNING, ORGANIZING, IMPLEMENTING & CONTROLLING A PROGRAM

- DERIVED INFORMATION SHOULD BE UTILIZED TO FOCUS THE PROJECT TEAM

- PROVIDES HEALTH INDICATORS FOR SHORT & LONG RANGE OBJECTIVES OF THE PROGRAM

- DISCIPLINED PROCESS TO EXPECT THE UNEXPECTED

- ORGANIZED FRAMEWORK TO DETERMINE THE DISCRETE STEPS TOWARD RISK RESOLUTION

- PROVIDES PATIENCE TO MANAGE TOWARD LONG TERM OBJECTIVES

FUNDAMENTALS OF RISK MITIGATION APPROACH

IMPLEMENTED IMMEDIATELY UPON SELECTION

– RECRUIT, EMPOWER & NURTURE A SINGLE, UNIFIED “A TEAM”
  - BUILD CONFIDENCE IN ABILITY TO MEET CHALLENGES
  - DEPLOY A STRONG TECHNICAL “SAFETY NET” OF EXPERIENCED SYSTEM & PERFORMANCE ASSURANCE ENGINEERS
  - FOSTER AWARENESS OF COLLATERAL IMPLICATIONS OF ACTION/NON-ACTION

– UNDERSTAND TEAM & SUPPLIER STRENGTHS & WEAKNESSES AND INTERNAL OPERATING PLAN
  - PLAN TO ADDRESS WEAKNESSES

– EXTENSIVE PEER REVIEW PROCESS WITH OUTSIDE EXPERTS
  - ATTENTION TO PROVEN BEST PRACTICES AND PROCESSES

– MONITOR ONGOING PREDICTIONS OF EXPECTED MISSION PERFORMANCE VS BASELINE & MINIMUM SCIENCE MISSION
  - STRIVE FOR ROBUST TECHNICAL RESOURCE MARGINS

FUNDAMENTALS
(CONTINUED)

- DEVELOP & CONSERVE SCHEDULE & BUDGET CONTINGENCY FOR EACH WBS ELEMENT TO MEET FUTURE CHALLENGES
  - ESTABLISH FIRM CONTROL TARGETS AS METRICS
  - UNDERSTAND TOLERANCE LIMITS AND TRIGGER POINTS
- FOCUS ON TIMELY & SUFFICIENT CLOSURE OF ACTIVITIES WITHOUT OVERREACTION TO PROGRAM PRESSURES
  - KEEP EYE ON THE GOAL LINE
  - DON'T BE "PENNY-WISE & POUND-FOOLISH"
- EXPEDITE BREADBOARDS & ENGINEERING TEST UNITS
  - PRE-TEST AS MANY INTERFACES AS POSSIBLE DURING THE COURSE OF COMPONENT DEVELOPMENT
- DRIVE TO SYSTEM-LEVEL PERFORMANCE TESTING ASAP
  - KEEP NECESSARY & PRUDENT LOWER-LEVEL QUALIFICATION
  - BUILD FLEXIBILITY INTO INTEGRATION & TEST FLOWS

ACHIEVEMENT OF AGGRESSIVE GOALS IS IN THE DETAILS

SUPPLIER INTEGRATION

- PREMISE: SUPPLIERS ARE PART OF THE MAP TEAM
  - MISSION SUCCESS DEPENDS ON QUALITY COMPONENTS
  - PROGRAMMATIC SUCCESS REQUIRES COMMUNICATION
- MAJOR COMPONENT RFPs ESTABLISHED VALUES
  - ROBUSTNESS OF DESIGN
  - CUSTOMER INSIGHT
  - TIMELY DELIVERIES
- WELCOMED TO THE TEAM UPON SELECTION
  - LETTER FROM PROJECT MANAGER
  - KICK-OFF MEETINGS INCLUDING A MISSION BRIEFING
  - MEETINGS WITH EXECUTIVE MANAGEMENT TO ESTABLISH POSITIVE RELATIONSHIP FROM THE OUTSET
- PLAN TO KEEP SUPPLIERS INFORMED OF MISSION PROGRESS AND COMMUNITY EXPECTATIONS

SUPPLIER INTEGRATION
(CONTINUED)

- KEY SUPPLIERS CAN COME IN SMALL PACKAGES
  - INTERPOINT POWER CONVERTERS
  - CANSTAR FIBER OPTIC STAR COUPLERS
- FREQUENT VISITS TO SUPPLIER SITES
  - TECHNICAL MONITOR TRAINING IS CRITICAL
    - HOW TO FOSTER DESIRED RELATIONSHIP
    - HOW TO GAIN SUFFICIENT INSIGHT
    - WHAT QUALITY INDICATORS TO LOOK FOR

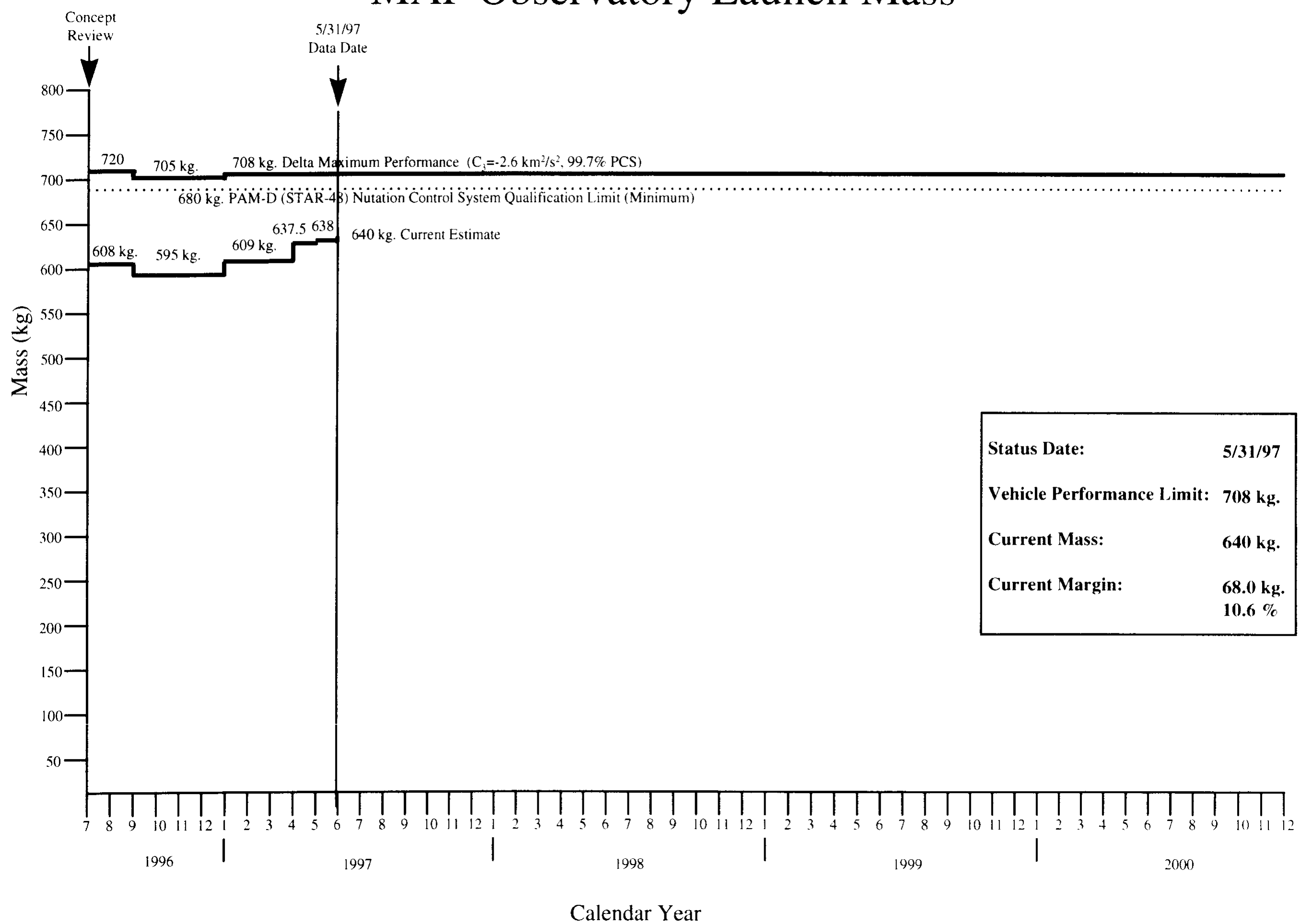
VERY IMPORTANT INVESTMENT OF TIME & MONEY

- PLANNED SUPPLIER EVENTS
  - SUPPLIER CONFERENCE AT GODDARD
    - TOUR OF GODDARD FACILITIES AND MAP HARDWARE
    - SOLICIT SUPPLIER FEEDBACK ON CUSTOMER PERFORMANCE
  - INVITATION TO LAUNCH EVENTS
  - NASA HONOR AWARDS IF PERFORMANCE WARRANTS

TECHNICAL RESOURCE RISK MANAGEMENT

- POWER AND PROPELLANT MARGINS ARE GOOD
- MASS IS THE MOST RESTRICTIVE RESOURCE
  - TRACKED MONTHLY
  - TIME-PHASED MASS MARGIN RELEASE PLAN ESTABLISHED TO PROVIDE MONTHLY ACTION THRESHOLD
- CURRENT MASS MARGIN (11.4%) IS ADEQUATE GIVEN ADVANCED PROJECT MATURITY
  - MANY MEASURED & CALCULATED VALUES
  - SCRUTINIZED BASIS OF ESTIMATES
  - **MUST MEET AGREED MAXIMUM LAUNCH MASS WITH BALLAST IF FINAL MASS IS LESS**
- LIMITED MASS RESTRICTS ABILITY TO ADD SELECTIVE REDUNDANCY

MAP Observatory Launch Mass



Status Date:	**5/31/97**
Vehicle Performance Limit:	**708 kg.**
Current Mass:	**640 kg.**
Current Margin:	**68.0 kg.** **10.6 %**

Mass Descope Summary

Descope	**Mass Savings**	**Impacts**
Delete one or more differencing assemblies, while maintaining performance above the minimum science floor	9-42 kg, depending on descope selected	Science performance degradation in sensitivity and/or Galactic siginal rejection
Use berylium-Al heat sinks (instead of Aluminum) in selected Instrument electronics locations	2-3 kg	Cost
Reduce daily 20 minute launch window to 3 minutes	3 kg	Higher probability of launch delay
Reduce monthly launch window to eliminate 2-loop scenarios (~2 weeks)	4 kg	Higher probability of launch delay
Accept 95% PCS (vs. 99%)	10 kg	Higher probability of injection failure

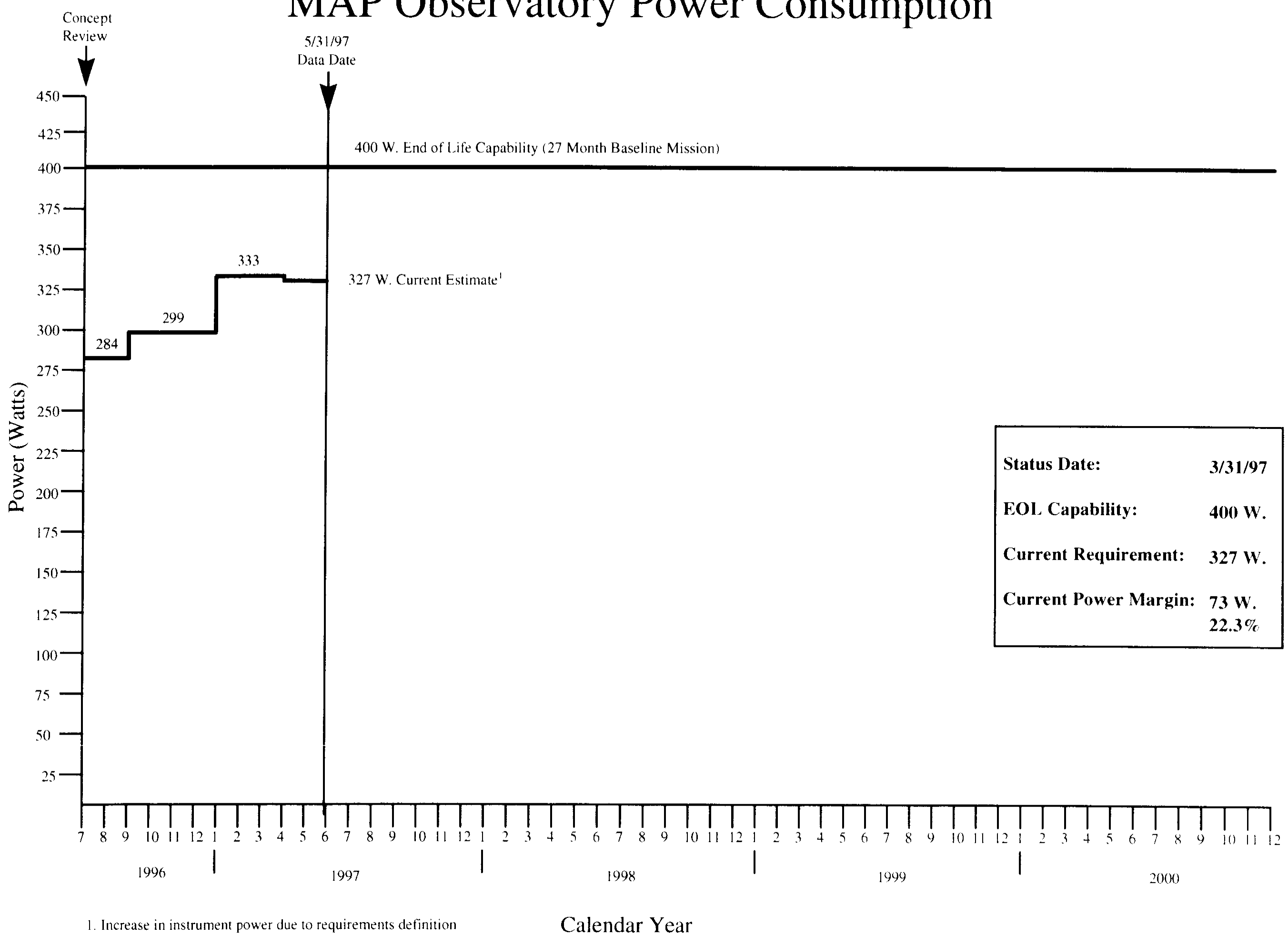
Instrument Descope Summary

	Case 1: Delete Ka DA (kg)	Case 2: Delete 1 Q DA (kg)	Case 3: Delete 1 V DA (kg)	Case 4: Delete Ka DA and 1 Q DA (kg)	Case 5: Delete 2 W DAs (kg)
DAs	4.2	3.4	2.6	7.6	4.8
Feeds	1.7	1.4	1.1	3.1	0.74
MS Structure	2	1.6	1.2	3.6	2.4
Bolts, tiedowns,etc.	0.5	0.5	0.5	1	1
Thermal Straps	0.35	0.35	0.35	0.7	0.7
Harness (Instr. & S/C)	3.2	3.3	3.3	6.5	6.6
AEU/DEU	0	0	0	0	1.1
PDU	0	0	0	0	2.3
Total (kg)	11.9	10.6	9.0	22.5	19.7
Science Impact	Reduced Galactic rejection	Reduced sensitivity; see plot	Reduced sensitivity; see plot	Reduced sensitivity & Galactic rejection; see	Reduced sensitivity; see plot

MASS RISK MITIGATION

- ESTABLISHED LIEN IN POP 97-1 FOR POTENTIAL AUGMENTATION OF LAUNCH VEHICLE
  - FOURTH GRAPHITE EPOXY MOTOR ADDS UP TO 100 KG OF PERFORMANCE TO REQUIRED TRAJECTORY
- PRELIMINARY ASSESSMENTS BY MCDONNELL DOUGLAS & GODDARD CONFIRM FEASIBILITY
- OPENS UP POSSIBILITIES TO CONSIDER RELIABILITY ENHANCEMENT OPTIONS IF WARRANTED AND OTHER RESOURCES PERMIT
- DECISION POINT IS LAUNCH VEHICLE TURN-ON (L-30 MONTHS)

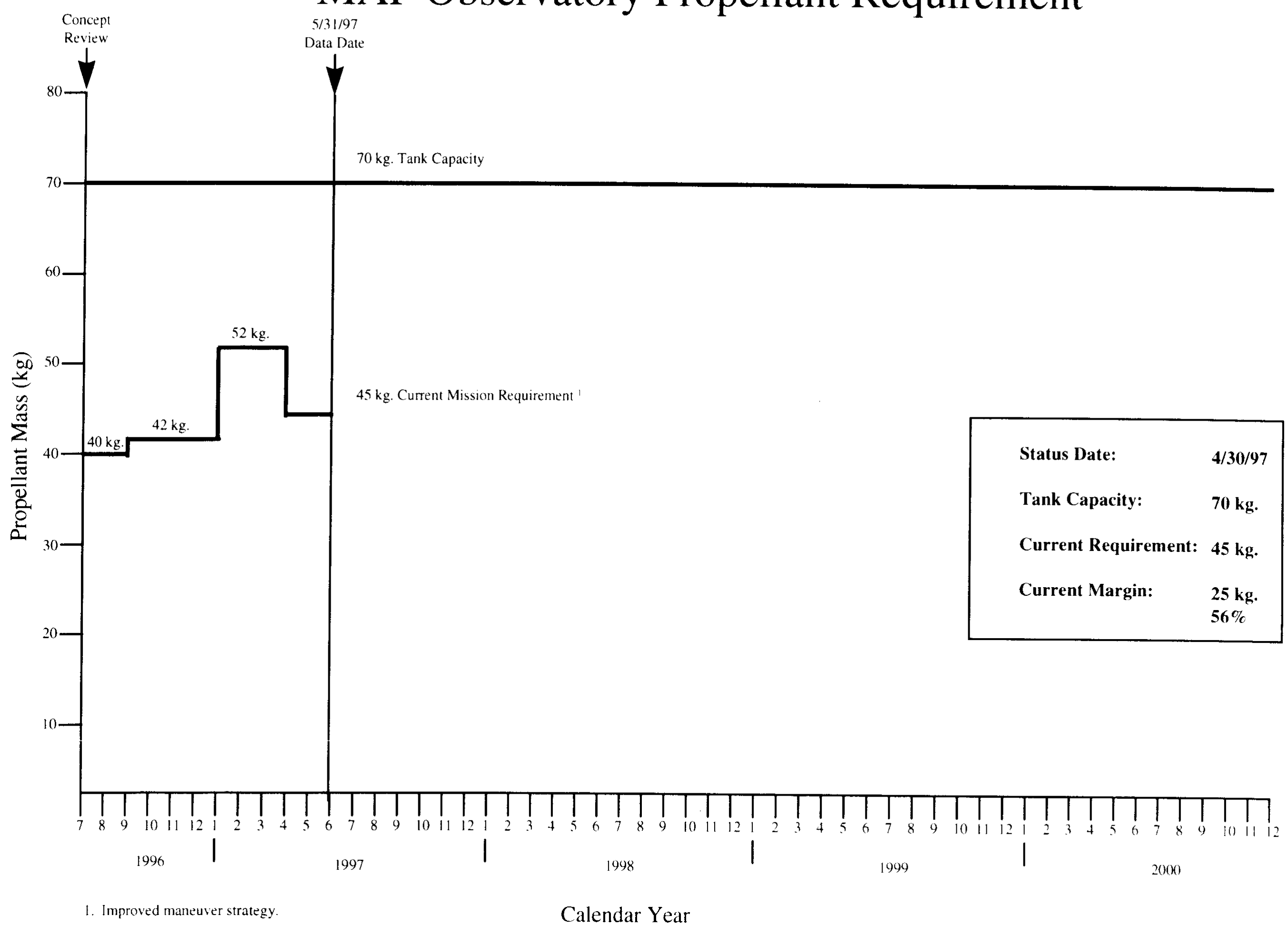
MAP Observatory Power Consumption



Status Date:	**3/31/97**
EOL Capability:	**400 W.**
Current Requirement:	**327 W.**
Current Power Margin:	**73 W. 22.3%**

1. Increase in instrument power due to requirements definition and parts radiation issues.

MAP Observatory Propellant Requirement



1. Improved maneuver strategy.

MAP CRITICAL PATH ASSESSMENT

Risk Management

Amplifier Build/Test (2/11/98) → Diff. Assembly Build/Test (11/1/98) → Instrument Integ. & Test (4/30/99) → System-level Integ. & Test (2/1/00) → 4 Mos. Baseline Sched. Reserve on Ship Date (6/1/00) → **LAUNCH** 8/25/00

- THE FINAL 2 OF 10 DIFFERENCING ASSEMBLY (DA) DELIVERIES DRIVE INSTRUMENT I&T
  - – DA BUILD BEGINS WITH A MATCHED SET OF AMPLIFIERS
  - – PLAN REQUIRES DELIVERY OF 10 DAs BY 1 NOV 98
- START-UP AND PROCESS ISSUES HAVE DELAYED EARLY AMPLIFIER DELIVERIES RELATIVE TO SCHEDULE BASELINE
  - – FIRST SET (4) OF FLIGHT AMPLIFIERS NOW EXPECTED 30 JUNE 97
  - – PLAN REQUIRES 80 FLIGHT AMPLIFIERS BY 11 FEB 98
- MICROWAVE COMPONENT PROCUREMENTS FOR DAs ARE ALSO BEHIND DUE TO UNEXPECTED CHALLENGES IN MECHANICAL DESIGN AND PACKAGING OF DAs IN THE INSTRUMENT STRUCTURE

SCHEDULE RISK MITIGATION

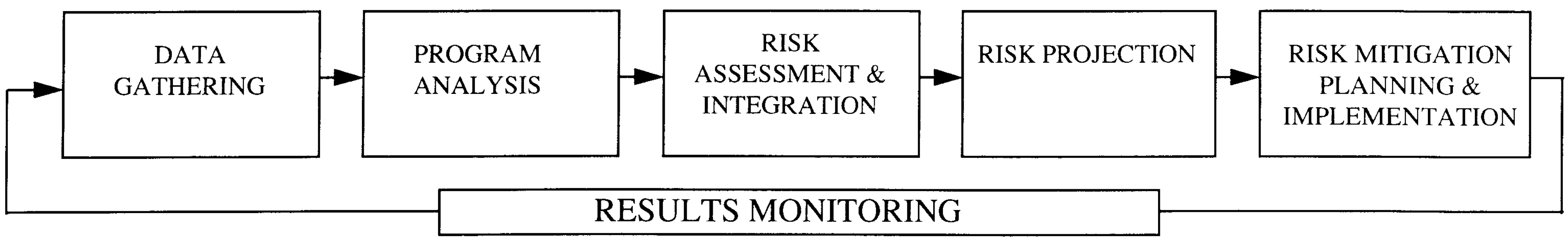
Risk Management

- ASSESSMENT OF SCHEDULE RESERVE
  - INSTRUMENT DEVELOPMENT IS CURRENTLY 2 MONTHS BEHIND BASELINE PLAN
  - TEAM IS COMMITTED AND CAPABLE OF RECOVERING LOST TIME
  - WATERFALL PRODUCTION SCHEDULES ALLOW THE COLLECTION OF RELIABLE SCHEDULE METRICS
    - METRICS WILL BE USED TO ASSESS NECESSITY TO DESCOPE NUMBER OF CHANNELS TO MAINTAIN LAUNCH SCHEDULE
  - AMPLIFIER & DIFFERENCING ASSEMBLY PROGRESS AND COMPLETION PROJECTIONS WILL BE FORMALLY REVIEWED:
    - 26 OCTOBER 1997 FOR POSSIBLE REPRIORITIZATION OF AMPLIFIER AND DIFFERENCING ASSEMBLY BUILD SCHEDULE
    - 8 DECEMBER 1997 FOR POSSIBLE AMPLIFIER OR DIFFERENCING ASSEMBLY REPRIORITIZATION OR DESCOPE OF CHANNELS
    - 15 APRIL 1998 FOR POSSIBLE DIFFERENCING ASSEMBLY REPRIORITIZATION OR DESCOPE OF CHANNELS
    - 15 JUNE 1998 FOR POSSIBLE DESCOPE OF CHANNELS

COST RISK MANAGEMENT

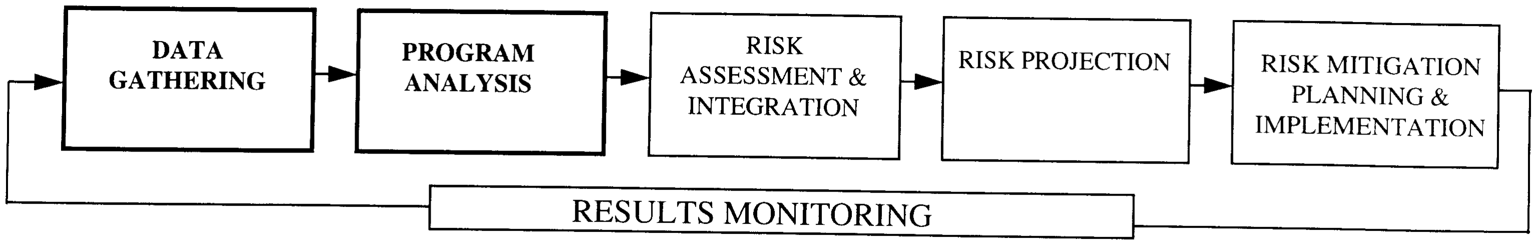
- EMPHASIS IS ON GENERATING & CONSERVING CONTINGENCY
  - THE FEW COMPONENTS OR ACTIVITIES WHICH CAN BE DELETED WILL NOT RECOVER LARGE AMOUNTS
- 30.8% CONTINGENCY ON COST TO COMPLETE
  - 20.1% UNLIENED CONTINGENCY ON COST TO COMPLETE
- PROVEN BUDGET PLANNING AND CONTROL PROCESS IS IN PLACE
- MAINTAINING SCHEDULE IS THE SINGLE LARGEST FACTOR IN COST CONTAINMENT
  - DESCOPE PLANNING FOCUSED ON MAINTAINING SCHEDULE

RISK MANAGEMENT
AN ONGOING PROCESS



RISK MANAGEMENT PROCESS

Risk Management



DATA GATHERING

- MBWA
- ONSITE SUPPLIER VISITS
- LOCAL FAB. VISITS
- SUBSYSTEM PEER REVIEWS
- COMPONENT REVIEWS
- MILESTONE PERF./TRENDING
- SCHED. SLACK CHANGES/TREND
- CHANGES IN S/W BUILD FUNCT.
- CCR ACTIVITY
- MEMORY UTILIZATION STATUS
- DRAWING RELEASE STATUS
- ANOMALY REPORTS
- MASS MARGIN STATUS/TREND
- EEE PARTS TRACKING REPORT
- ANALYSIS RESULTS
- EXPERT INTERVIEWS
- LESSONS LEARNED
- FMEA'S, REL. DIAGRAMS
- POWER MARGIN STAT/TREND
- CDRL STATUS MATRIX
- STAFF MEETINGS
- SYSTEM DEV. MEETINGS
- PROJECT TEAM ASSESSMENTS
- DAILY I&T MEETINGS
- SUPPLIER TELECONS
- MAJOR SYSTEM REVIEWS
- MEETINGS WITH FUNCT. MGMT.
- ANALYSIS RESULTS
- QA AUDITS
- TEST RESULTS

PROGRAM ANALYSIS

- 533/CTC
- % COMPLETE
- COST TO DATE
- RUDAMENTARY EARNED VALUE
- MILESTONE ANALYSIS
- CRITICAL PATH METHOD
- TECH. RES. MARGIN ASSESSMENT
- CHANGE TRAFFIC METRICS
- PARAMETRIC COST MODELING

RISK MANAGEMENT PROCESS (CONTINUED)

DATA GATHERING → PROGRAM ANALYSIS → **RISK ASSESSMENT & INTEGRATION** → RISK PROJECTION → RISK MITIGATION PLANNING & IMPLEMENTATION

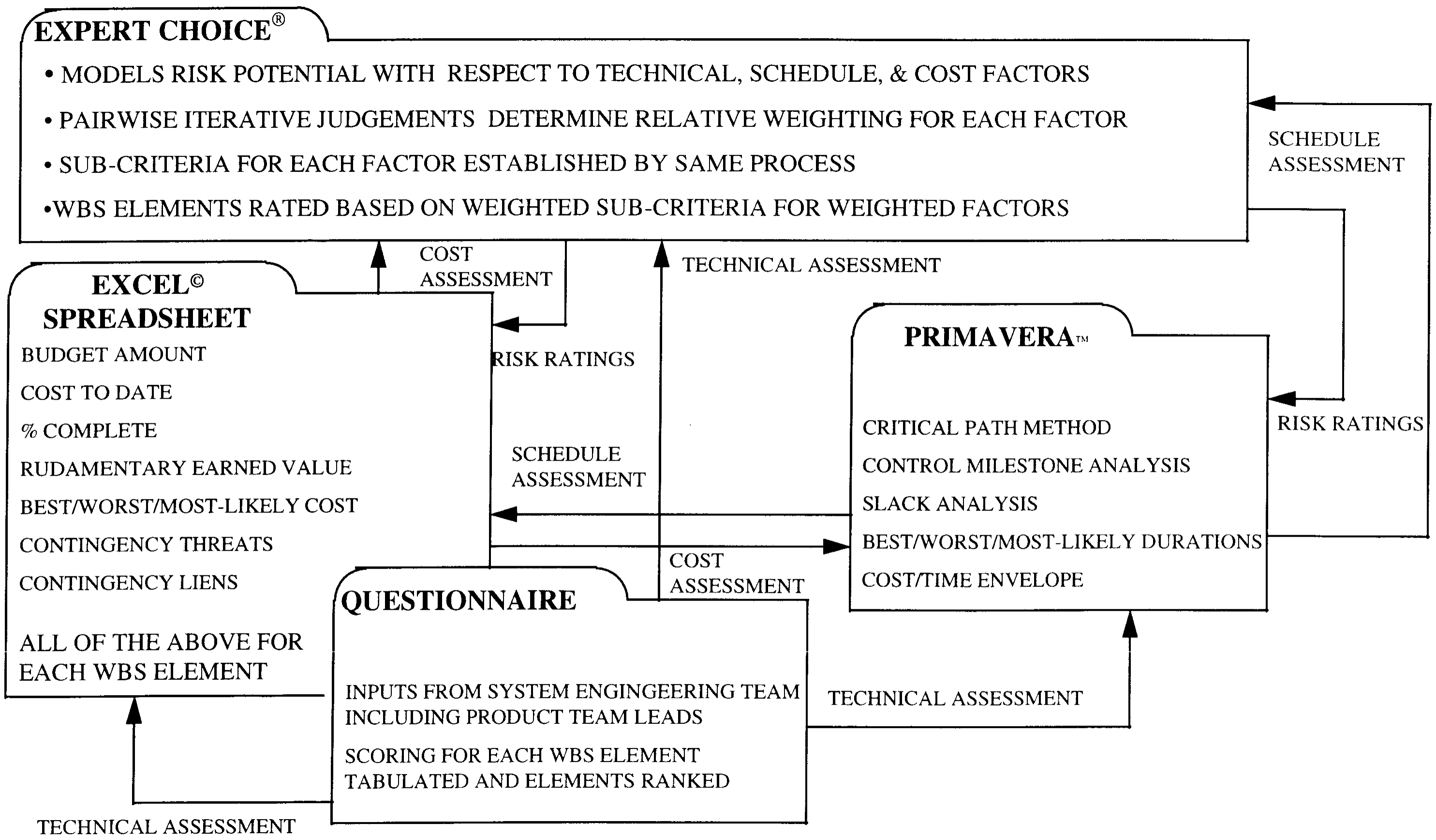
RESULTS MONITORING

GOAL

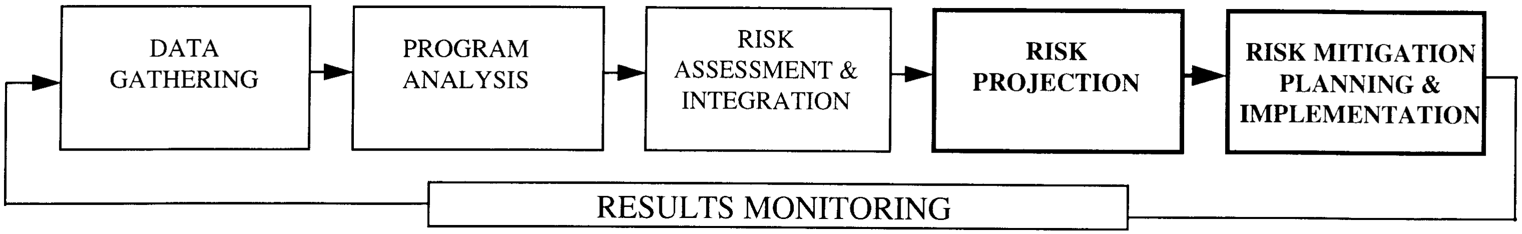
- TECHNICAL RISK
  - MINIMUM MISSION
  - BASELINE MISSION
  - MODERATE
  - LOW
  - COMPLETE
- SCHEDULE RISK
  - LAUNCH IMPACT
  - LAUNCH THREAT
  - MARGINAL SLACK
  - GOOD SLACK
  - COMPLETE
- COST RISK
  - COST CAP THREAT
  - CONTINGENCY LIEN
  - OVER PLAN
  - ON PLAN
  - COMPLETE

RISK ASSESSEMENT AND RISK INTEGRATION

Risk Management



RISK MANAGEMENT PROCESS (CONTINUED)



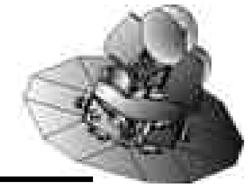
RISK PROJECTION

- TECHNICAL RISK PROJECTION (PROGRAM WATCH LIST)
- SCHEDULE AT COMPLETION SIMULATIONS USING MONTE CARLO FOR PRIMAVERA™
  - BEST/WORST CASE
  - MEAN
  - PROBABILITY DISTRIBUTION
  - % CRITICALITY
- COST AT COMPLETION SIMULATIONS USING CRYSTAL BALL©
  - MEAN PROBABILITY DISTRIBUTION
- COST/TIME ENVELOP USING MONTE CARLO FOR PRIMAVERA™

MITIGATION PLANNING AND RISK IMPLEMENTATION

- REALLOCATION OF CONTINGENCY
- SCHEDULE REPLANNING
- ADJUSTMENT OF TEAM PRIORITIES
- REALLOCATION OF HUMAN RESOURCES
- MANAGEMENT REPORTING
- REDUCE SCOPE
- INCREASE SCOPE
- SPECIFIC ACTIONS TRACKED FOR EACH IDENTIFIED RISK
- UPDATE WATCH LISTS
- INITIATE PARALLEL DEVELOPMENT ACTIVITIES ESTABLISHMENT OF CONTROL MILESTONES

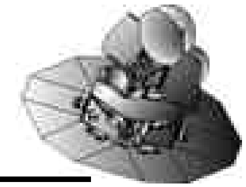
TOP 5 RISK AREAS
JUNE 1997



Risk Management

Questionnaire (Technical Bias)	Primavera™ (Schedule Bias)	Spreadsheet (Cost Bias)	Expert Choice® (Weighted Assessment)
1. Instrument Assembly	Amplifiers	Instrument Assembly	Amplifiers
2. Amplifiers	Differencing Assemblies	MPS Assessment	Differencing Assemblies
3. Differencing Assemblies	Thermal Reflector System	Power Distribution Unit	Instrument Assembly
4. Gen. IV TDRS Transponder	Power Distribution Unit	Instrument Structure	Power Distribution Unit
5. Power Distribution Unit	Instrument Assembly	ACE/C&DH	Thermal Reflector System

TOP 5 RISKS & MITIGATIONS

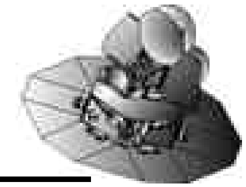


Risk Management

RISK ITEM DESCRIPTION	**RISK**	**MITIGATION**
AMPLIFIERS (90 GHz PERFORMANCE COLD, PRODUCTION PROCESS CONTROL & SCHEDULE)	TECHNICAL & SCHEDULE	VIBRATION OF TYP. NRAO AMP (6/96) PRE-PROTOTYPE (7/96) & PROTOTYPE AMPLIFIERS TO PRINCETON (3/97) GODDARD QA UMBRELLA (ONGOING) SCIENCE DESCOPE OPTIONS
DIFFERENCING ASSEMBLIES (MAINTAINING PHASE MATCHING THROUGH LAUNCH, PRODUCTION SCHEDULE	TECHICAL & SCHEDULE	PERFORMANCE & ENVIRONMENTAL TESTS OF PROTOTYPE UNITS (7/97) VIBRATION TEST OF EACH FLIGHT DA PRIOR TO INSTRUMENT INTEGRATION SCIENCE DESCOPE OPTIONS
INSTRUMENT ASSEMBLY (INTEGRATION OF DAs INTO FPA/RXB STRUCTURE WITH HARNESS, MLI, ECOSORB, ETC.)	TECHNICAL & SCHEDULE	DA MASS MODEL VIB (6/97) DA QUAL UNIT VIB (7/97) CAD SIMULATED ASSEMBLY (8/97) STRUCT. QUAL W/ 10 DA HI-FI MOCKUPS (12/97)
POWER DISTRIBUTION UNIT (NOISE PERFORMANCE AS INSTALLED IN OBSERVATORY)	TECHNICAL	LOW NOISE VERIFICATION UNIT I/F TEST WITH DA (7/97) DESIGN & RELIABILITY REVIEWS AND NOISE & EMI TIGER TEAM (ONGOING)
THERMAL REFLECTOR (DESIGN VERIFICATION, FABRICATION AND COATING CONCERNS)	TECHNICAL	REFLECTOR EVALUATION UNIT AS A MANUFACTURING & PERFORMANCE PATHFINDER (11/97)

SCIENCE DESCOPE PLAN

- ERROR BAR IN MODEL POWER SPECTRA DEFINES MAP SCIENCE RETURN
  - REPRESENTS THE ULTIMATE SCHEDULE & COST RISK MITIGATION OPTION
- MINIMUM SCIENCE MISSION PERMITS SIGNIFICANT DESCOPE FLEXIBILITY
  - NUMBER OF CHANNELS
  - SENSITIVITY
- CAN SHAPE DETAILS OF DESCOPE OPTIONS TO REALITY OF A WIDE RANGE OF POTENTIAL CHALLENGES
  - DON’T NEED TO HOLD UP INSTRUMENT I&T FOR LAST DIFFERENCING ASSEMBLY DELIVERIES
  - DON’T NEED TO LAUNCH WITH ALL CHANNELS WORKING



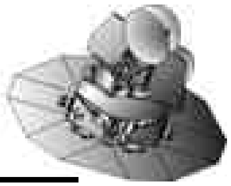
SUMMARY

- TECHNICAL RISKS HAVE BEEN MITIGATED
  - AGGRESSIVE DEVELOPMENT SCHEDULES
  - EXTENSIVE USE OF PEER REVIEWS
  - ENGINEERING TEST UNITS & TEST PROGRAM
- SCHEDULE RISK IS UNDERSTOOD
  - NATURE OF FAST TRACK PROGRAMS
  - CONTROL MILESTONES & FIRM DECISION POINTS
  - ABILITY TO DESCOPE TO MAINTAIN SCHEDULE
- COST RISKS ARE CONTAINED
  - RIGOROUS PLANNING & CONTROL
  - SUFFICIENT CONTINGENCY
- ROBUST DESCOPE CAPABILITY
  - SUBSTANTIAL MARGIN BETWEEN MINIMUM SCIENCE MISSION AND CURRENT EXPECTATION

SUMMARY

RICHARD DAY
PROJECT MANAGER

ACCOMPLISHMENTS



Summary

- WE HAVE FORMED A STRONG, INTEGRATED MISSION TEAM
- MANAGEMENT AND SYSTEM ENGINEERING PROCESSES ARE IN PLACE TO DEVELOP AND OPERATE THE MISSION
- MISSION REQUIREMENTS ARE THOROUGHLY UNDERSTOOD AND STABLE
- THE MISSION DESIGN MEETS MISSION REQUIREMENTS
- IN A PERIOD OF JUST OVER 1 YEAR, WE HAVE ADVANCED ALL MAJOR COMPONENTS TO AT LEAST THE ENGINEERING TEST UNIT MATURITY LEVEL
- COST ESTIMATE, SCHEDULE AND CONTROL PROCESSES PROVIDE AN EXTREMELY HIGH PROBABILITY THAT THE MISSION WILL REMAIN WITHIN THE COST CAP